



Technologies for Climate Change Adaptation - Agriculture Sector

Zhu, Xianli; Clements, Rebecca; Hagggar, Jeremy; Quezada, Alicia; Torres, Juan

Publication date:
2011

Document Version
Publisher's PDF, also known as Version of record

[Link back to DTU Orbit](#)

Citation (APA):
Zhu, X., Clements, R., Hagggar, J., Quezada, A., & Torres, J. (2011). *Technologies for Climate Change Adaptation - Agriculture Sector*. Danmarks Tekniske Universitet, Risø Nationallaboratoriet for Bæredygtig Energi. TNA Guidebook Series

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Technologies for Climate Change Adaptation

– Agriculture Sector –



Technologies for Climate Change Adaptation

– Agriculture Sector –

Authors

Rebecca Clements

Practical Action Latin America

Jeremy Haggar

University of Greenwich

Alicia Quezada

Practical Action Latin America

Juan Torres

Practical Action Latin America

Editor

Xianli Zhu

UNEP Risø Centre

Reviewed by

Bernd R. Eggen

Abdul Rasack Houssein Nayamuth

Jørgen Eivind Olsen

Sara Lærke Meltotte Trærup

August 2011



UNEP Risø Centre on Energy, Climate and Sustainable Development
Risø DTU National Laboratory for Sustainable Energy
P.O. Box 49,
4000, Roskilde
Denmark
Phone +45 4677 5129
Fax +45 4632 1999
<http://www.uneprisoe.org/>
<http://tech-action.org/>

ISBN: 978-87-550-3927-8

Design and production:
Magnum Custom Publishing
New Delhi, India
info@magnumbooks.org

Photo acknowledgement:

Front cover photo – Bali rice terrace, Indonesia, courtesy of Chensiyuan, Creative Commons
3.0 Unported

Back cover photo – Grazing cattle herd in Hawaii, USA, courtesy of Forest & Kim Starr, Creative Commons
3.0 Unported

This guidebook can be downloaded from <http://tech-action.org/>

Please use the following reference when quoting the guidebook:

Clements, R., J. Hagggar, A. Quezada, and J. Torres (2011). Technologies for Climate Change Adaptation – Agriculture Sector. X. Zhu (Ed.). UNEP Risø Centre, Roskilde, 2011

Disclaimer:

This guidebook is intended to assist developing country governments, agriculture practitioners, and stakeholders in conducting Technology needs Assessment (TNA) and prepare technology action plans for adaptation to climate change in the agriculture sector under the Global Environment Facility (GEF) funded TNA project, implemented by UNEP and URC. The findings, suggestions, and conclusions presented in this publication are entirely those of the authors and should not be attributed in any manner to the GEF or UNEP.

Contents

<i>List of Tables, Figures and Boxes</i>	<i>v</i>
<i>Abbreviations</i>	<i>ix</i>
<i>Preface</i>	<i>xi</i>
<i>Acknowledgements</i>	<i>xiii</i>
<i>Executive Summary</i>	<i>xv</i>
1. Introduction and Outline of the Guidebook	1
2. Background	5
2.1 Key Concepts	5
2.2. Agricultural Production Systems	16
2.3 Levels of Adaptation	22
3. Adaptation Decision-making and Prioritisation of Technologies	27
3.1 Vulnerability and Risk Assessment	27
3.2 Identifying Options for Adaptation	28
3.3 Key Criteria for Prioritisation of Adaptation Technologies	31
4. Concrete Adaptation Technologies and Practices in the Agriculture Sector	35
4.1 Planning for Climate Change and Variability	36
4.1.1 Climate Change Monitoring System	36
4.1.2 Seasonal to Interannual Prediction	43
4.1.3 Decentralised Community-run Early Warning Systems	50
4.1.4 Index-based Climate Insurance	54
4.2 Technologies for Sustainable Water Use and Management	59
4.2.1 Sprinkler and Drip Irrigation	60
4.2.2 Fog Harvesting	71
4.2.3 Rainwater Harvesting	76
4.3 Soil Management	85
4.3.1 Slow-forming Terraces	85
4.3.2 Conservation Tillage	91
4.3.3 Integrated Nutrient Management	97

4.4	Sustainable Crop Management	103
4.4.1	Crop Diversification and New Varieties	104
4.4.2	Biotechnology for Climate Change Adaptation of Crops	110
4.4.3	Ecological Pest Management	116
4.4.4	Seed and Grain Storage	123
4.5	Sustainable Livestock Management	130
4.5.1	Livestock Disease Management	130
4.5.2	Selective Breeding via Controlled Mating	136
4.6	Sustainable Farming Systems	139
4.6.1	Mixed Farming	140
4.6.2	Agro-forestry	143
4.7	Capacity Building and Stakeholder Organisation	152
4.7.1	Community-based Agricultural Extension Agents	152
4.7.2	Farmer Field Schools	156
4.7.3	Forest User Groups	161
4.7.4	Water User Associations	165
5.	Conclusions	171
	References	175
	Appendix I – Glossary	195
	Appendix II – Recommended Sources for Additional Information	197

List of Tables, Figures and Boxes

List of Tables

Table 1.1	Overview of Technologies Covered in the Guidebook
Table 2.1	Climate Change Impacts on Agriculture
Table 2.2	Examples of Resources Affecting Adaptive Capacity
Table 4.1	Adaptation Technologies
Table 4.2	Essential Climate Variables
Table 4.3	Agricultural Decisions and Climate Forecasts
Table 4.4	Countries Using SIP Products from Global Producers
Table 4.5	Indicative Costs for Implementation and Maintenance of Community Early Warning System
Table 4.6	Summary of Climate Insurance Products for Agriculture
Table 4.7	Efficiencies of Sprinkler Irrigation in Different Climates
Table 4.8	Response of Different Crops to Sprinkler Irrigation Systems
Table 4.9	Water Collection Rates from Fog Collectors
Table 4.10	Budget Breakdown Rainwater Harvesting in Bhutan
Table 4.11	Activity Costs for Rainwater Harvesting Pilot Scheme in Burundi
Table 4.12	Crop Yields (kg/ha) for the Main Crops in La Encañada, Peru
Table 4.13	Crop Yields (t/ha) in the Community of Chullpa K'asa, Bolivia
Table 4.14	Average Cost of Fertilisers Per Metric Ton in Africa
Table 4.15	Terms Related to Biotechnology
Table 4.16	Biotechnology Products Showing Longer-term Promise for Adaptation to Climate Change
Table 4.17	Storage Characteristics of Selected Food Commodities
Table 4.18	Traditional and Improved Storage Methods
Table 4.19	Agro-forestry Diagnosis and Design
Table 4.20	Key Institutions for Agro-forestry
Table 4.21	Agro-forestry Project Costs in Eritrea
Table 4.22	Agro-forestry Project Costs in Senegal

List of Figures

- Figure 2.1 Linkages between Ecosystem Services and Human Well-being.
- Figure 2.2 Vulnerability to Climate Change Divided into its Components of Exposure, Sensitivity and Adaptive Capacity
- Figure 2.3 Traditional Agricultural Practices
- Figure 2.4 Relationship between the Agro-biodiversity of Potatoes and Risks
- Figure 2.5 Diversified Cultivation and Conservation of Native Varieties: a Household Climate Change Adaptation Strategy in the High Mountain Ecosystem
- Figure 3.1 How Community-based Adaptation (CBA) Could Be Implemented, Engaging Civil Society in Planning, Monitoring and Implementation
- Figure 4.1 WMO Global Producing Centres (GPCs) of Long Range Forecasts
- Figure 4.2 Farmland Sprinkler System
- Figure 4.3 Drip Irrigation System for an Olive Tree Farm in Ica Valley, Peru
- Figure 4.4 Capers Field under Drip Irrigation System in Sandy Soil Pisco Valley Peru
- Figure 4.5 Schematic of a Typical Rainwater Catchment System
- Figure 4.6 Ground Catchment System
- Figure 4.7 Rock Catchment
- Figure 4.8 Structure of Slow-forming Terraces
- Figure 4.9 Planting Hedgegrows along Sloping Agriculture Land
- Figure 4.10 Hoeing in India
- Figure 4.11 Animal Traction in Nepal
- Figure 4.12 Conservation Tillage Using Discs and Tines
- Figure 4.13 Ridge Tillage
- Figure 4.14 Effect of Potassium Application on Frost Injury to Potato Crop
- Figure 4.15 IPM Vegetable Production in Nicaragua
- Figure 4.16 Holistic Approaches to Disease Prevention and Control
- Figure 4.17 Holistic Approaches to Disease Prevention and Control
- Figure 4.18 Farmer Centre in Peru Where Local Agricultural Extension Agents Are Trained

List of Boxes

- Box 2.1 Common Features of Biodiverse Farms
- Box 2.2 Agroecological Approaches That Build Resilience
- Box 2.3 The NAPA Process

Box 3.1	Resources for Vulnerability and Risk Assessment
Box 3.2	Incorporating Local Culture into Adaptation Strategies: Fish Harvesting and Floating Gardens in Bangladesh
Box 4.1	Traditional Forecasting with Bio-indicators
Box 4.2	FAO Climate Change and Agriculture Modelling
Box 4.3	Agricultural Climate Risk Zoning in Brazil
Box 4.4	Climate Change Monitoring in Kenya
Box 4.5	Seasonal Climate Forecasts in Lesotho
Box 4.6	Seasonal Climate Forecasts in Burkina Faso
Box 4.7	Changing Time of Planting and Harvesting Based on Early Warning Systems
Box 4.8	ENSO Insurance in Peru
Box 4.9	Insurance against Additional Costs of Irrigating Coffee in Vietnam
Box 4.10	Indexed Livestock Mortality Insurance in Mongolia
Box 4.11	Fondos in Mexico
Box 4.12	Sprinkler Irrigation in Zimbabwe
Box 4.13	Drip Irrigation for Olives in the Desert of Acari Valley, Peru
Box 4.14	Potential Application of Fog Harvesting Technology
Box 4.15	Key Information Requirements for Assessing Fog Harvesting Suitability
Box 4.16	Development of Fog Water Collection in Nepal
Box 4.17	Ground Surface Collection in Paraguay
Box 4.18	Knowledge Requirements for the Selection of Rainwater Harvesting Technology
Box 4.19	Rainwater Harvesting Project in the Philippines
Box 4.20	Rainwater Harvesting Realising the Potential of Rainfed Agriculture in India
Box 4.21	Conservation and Reclamation of Deteriorated Volcanic Soils in the Ecuadorian Andes
Box 4.22	Sloping Agricultural Land Technology
Box 4.23	Conservation Tillage in Brazil
Box 4.24	Ridge Tillage and Natural Vegetation Strips as Erosion Barriers in the Philippines
Box 4.25	On-farm Testing of Integrated Nutrient Management Strategies in Eastern Uganda
Box 4.26	Promotion of Integrated Nutrient Management in India
Box 4.27	Managing the Nutrient Balance of Organic Coffee Farms in Nicaragua
Box 4.28	Selection of Resistant Varieties of Potatoes (<i>Solanum</i> spp) for Seeds
Box 4.29	Crop Diversification to Cope with Drought in Zimbabwe
Box 4.30	Genetically Modified Insect-resistant Cotton in India

- Box 4.31 Drought-tolerant Maize for Asia
- Box 4.32 Drought-tolerant Rice for Asia
- Box 4.33 Farmer Field Schools: A Model Approach for Farmer Education on EPM
- Box 4.34 Large-scale Ecological Pest Management in Indonesia
- Box 4.35 Mobilising Integrated Pest Management (IPM) to Control the Cassava Mealy Bug in Africa
- Box 4.36 Planting of Fruit Trees in and around Crop Fields to Attract Predatory Birds in India
- Box 4.37 Push-pull Technology in Kenya
- Box 4.38 Experiment in Kenya – Cow Dung Ash and Airtight Storage Increase Seed Longevity
- Box 4.39 Improved Technologies for Reducing Post-harvest Losses in Afghanistan
- Box 4.40 Diffuse Light Storage
- Box 4.41 Control of Mastitis
- Box 4.42 The Role of Indigenous Knowledge in Livestock Disease Management under Climate Change
- Box 4.43 Control of Animal Diseases Related to Climate Changes: Rift Valley Fever
- Box 4.44 Controlled Alpaca Breeding in Peru
- Box 4.45 Advantages of Mixed Farming Systems for the Environment
- Box 4.46 Mixed Crop-livestock Farming and Climate Change in Africa
- Box 4.47 Advantages of Mixed Farming in Southern Honduras
- Box 4.48 Tree-based Agricultural Systems Improve Food Security and Livelihoods
- Box 4.49 Introducing Cactus-based Agro-forestry Practices to the Drylands
- Box 4.50 Coffee Agro-forestry for Adaptation to Climate Change in Chiapas, Mexico
- Box 4.51 Rural Extensionist Experiences from Bangladesh and Kenya
- Box 4.52 Farmer Field Schools on Sweet Potato Production in East Africa
- Box 4.53 Farmer Field Schools for Pest Management in Cocoa
- Box 4.54 Livelihoods and Forestry Programme in Nepal
- Box 4.55 Participatory Water Resource Monitoring Pangani Basin Water Management, Tanzania
- Box 4.56 Adapting to Climate Change with Water User Associations in the Great Ruaha River, Tanzania

Abbreviations

AfDB	African Development Bank
CBA	Community-based Adaptation
CBD	Convention on Biological Diversity
CBO	Community-based Organisations
CCD	Cold Cloud Duration
CGIAR	Consultative Group for International Agricultural Research
CIMMYT	International Maize and Wheat Research Centre
CIP	International Potato Centre in Peru
CO ₂	Carbon Dioxide
CRA	Community risk assessment
CVCA	Climate Vulnerability and Capacity Analysis
DFID	Department for International Development, UK
DIP	Deliberative inclusive processes
DLS	Diffuse light storage
DNA	Deoxyribonucleic acid
DRM	Disaster Risk Management
ECV	Essential Climate Variables
ENSO	El Niño Southern Oscillation
EPM	Ecological Pest Management
EWS	Early Warning System
FAO	United Nations Food and Agriculture Organisation
FFS	Farmer Field Schools
FUG	Forest User Groups
GCOS	Global Climate Observing System
GDP	Gross Domestic Product
GEOSS	Global Earth Observation System of Systems
GHF	Global Humanitarian Forum
GIS	Geographic Information System
GMO	Genetically Modified Organism
GPC	Global Producing Centres
IAAST	International Assessment of Agricultural, Science and Technology for Development
ICSU	International Council for Science

IDRC	International Development Research Centre
IDS	Institute of Development Studies, University of Sussex, UK
IFAD	International Fund for Agricultural Development
IFPRI	International Food Policy Research Institute
IFRC	International Federation of Red Cross and Red Crescent Societies
INM	Integrated Nutrient Management
IOC	Intergovernmental Oceanographic Commission
IPCC	Intergovernmental Panel on Climate Change
IPM	Integrated Pest Management
IRRI	International Rice Research Institute
ITDG	Intermediate Technology Development Group (currently Practical Action)
IUCN	International Union for Conservation of Nature
LDC	Least Developed Country
MDG	Millennium Development Goals
NAPA	National Adaptation Programme of Action
NDVI	Normalised Difference Vegetation Index
NGO	Non-governmental Organisation
NMHS	National Meteorological or Hydrometeorological Service
NTFP	Non-timber forest products
PCVA	Participatory Capacities and Vulnerabilities Assessment
PVA	Participatory Vulnerability Analysis
SARD	Sustainable Agriculture and Rural Development
SFC	Standard Fog Collectors
SIP	Seasonal to Interannual Prediction
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development
VCA	Vulnerability and capacity assessment
WMO	World Meteorological Organisation
WUA	Water User Association
WWF	World Wildlife Fund

Preface

The agriculture sector faces the daunting challenge of providing adequate food and other necessities to a growing world population, which is projected to increase to nine billion by 2050. There is limited scope for expansion of arable land, and the emerging threat to agriculture from climate change in the form of unpredictable weather, floods, and other disastrous events makes the task of providing enough food for the global population even more challenging. Since the agriculture sector is still one of the most important economic sectors in many developing countries – providing employment and the main source of income to the poor– it is not surprising that most developing countries are interested in technologies for adapting agriculture to climate change.

Technologies and practices do exist, or have been developed in different parts of the world, to facilitate adaptation to climate change in the agriculture sector. These range from improved weather forecasts to water conservation, drip irrigation, sustainable soil management, better livestock management, and change in crop types and planting, among others. Some of these measures may need investment while the others primarily require improving awareness and building capacity to deal with new practices.

This guidebook provides information on 22 technologies and options for adapting to climate change in the agriculture sector. It describes what policy makers, development planners, agriculture experts and other stakeholders in countries should consider while determining a technology development path in agriculture. NGOs, rural communities and agricultural practitioners could examine and include appropriate options in their portfolios of technologies and options for agriculture. The guidebook is expected to stimulate further work on identifying options for climate change adaptation in the agricultural sector in different parts of the world.

This guidebook has been co-authored by Rebecca Clements, Alicia Quezada, and Juan Torres from Practical Action Latin America and Jeremy Hagggar from the University of Greenwich, UK. Practical Action, prime contributor to this guidebook, has extensive field experiences in supporting poverty reduction activities in the agriculture sector in developing countries in Africa, Asia and South America. Jeremy Hagggar, Head of the Agriculture, Health and Environment Department at the Natural Resources Institute, University of Greenwich has more than 20 years of experience in research and capacity building on sustainable design and management of tropical agroecosystems in Central America and Mexico. He contributed as a reviewer of the book also.

The guidebook was reviewed by Abdul Rasack Houssein Nayamuth, an independent consultant from Mauritius, Jørgen Eivind Olsen from the Department of Agroecology and Environment at Århus University, Bernd R. Eggen – a climate consultant, and Sara Lærke Meltotte Trærup from the UNEP Risø Centre on Energy, Climate and Sustainable Development (URC). Their inputs were invaluable and deeply appreciated. Xianli Zhu from URC coordinated the guidebook's preparation.

This publication is part of a technical guidebook series produced by URC as part of the Technology Needs Assessment (TNA) Project (<http://tech-action.org/>). UNEP and URC are implementing the TNA Project in 36 developing countries. Funding for this project is provided by the Global Environment Facility (GEF).

Jyoti Prasad Painuly
Project Manager
UNEP Risø Centre

Mark Radka
Energy Programme Coordinator
UNEP DTIE

Acknowledgements

This guidebook is the fruit of cooperation and relentless dedication of many people, especially the authors and reviewers. I wish to thank them for their dedication and excellent work. Thanks to their vast experience and rich expertise on agriculture sector and climate change adaptation, we have been able to bring out this guidebook.

The authors and I would like to thank Rafael Galván, Dalia Carbonel, Stuart Coupe, Gregory Damman, Jon Ensor, Carlos de la Torre Postigo, Emiliano Mar, Roberto Montero, Daniel Rodriguez, Giannina Solari, Mark Turner, Juan Vargas, Alcides Vilela, and Nadya Villavicencio for the help they gave the three authors at the Latin America Office of Practical Action. Ximena Vidal helped with photos and figures, including obtaining use permission from the copyright owners.

I would like to express my gratitude to Derek Russell of Natural Resources Institute, University of Greenwich for contributing to the section on biotechnology and to Graham Thiele from the International Potato Center for contribution to the section on international research centres. Jessa Boanas-Dewes did the proof-reading and language editing of this guidebook.

I am grateful to colleagues at the UNEP Risø Centre for their support during the preparation of this guidebook. Majja Bertule and Susanne Haunstrup Kirkegaard at the Centre assisted me in the process.

Editor
Xianli Zhu
UNEP Risø Centre

Executive Summary

This guidebook presents a selection of technologies for climate change adaptation in the agriculture sector. A set of 22 adaptation technologies are showcased. These are based primarily on the principles of agroecology, but also include scientific technologies of climate and biological sciences complemented by important sociological and institutional capacity building processes that are required for climate change to function. The technologies cover:

- Planning for climate change and variability
- Sustainable water use and management
- Soil management
- Sustainable crop management
- Sustainable livestock management
- Sustainable farming systems
- Capacity building and stakeholder organisation.

Technologies that tend to homogenise the natural environment and agricultural production have low possibilities of success in environmental stress conditions that are likely to result from climate change. On the other hand, technologies that allow for, and promote diversity are more likely to provide a strategy which strengthens agricultural production in the face of uncertain future climate change scenarios. The 22 technologies showcased in this guidebook have been selected because they facilitate the conservation and restoration of diversity while also providing opportunities for increasing agricultural productivity. Many of these technologies are not new to agricultural production practices, but they are implemented based on the assessment of current and possible future impacts of climate change in a particular location. agroecology is an approach that encompasses concepts of sustainable production and biodiversity promotion and therefore provides a useful framework for identifying and selecting appropriate adaptation technologies for the agriculture sector.

The guidebook provides a systematic analysis of the most relevant information available on climate change adaptation technologies in the agriculture sector. It has been compiled based on a literature review of key publications, journal articles, and e-platforms, and by drawing on documented experiences sourced from a range of organisations working on projects and programmes concerned with climate change adaptation technologies in the agriculture sector. Its geographic scope focuses on developing countries where high levels of poverty, agricultural production, climate variability and biological diversity intersect.

Key concepts around climate change adaptation are not universally agreed on. It is therefore important to understand local contexts – especially social and cultural norms – when working with national and sub-national stakeholders to make informed decisions about appropriate technology options. Thus, decision-making processes should be participative, facilitated, and consensus-building oriented and should be based on the following key guiding principles:

- Increasing awareness and knowledge
- Strengthening institutions
- Protecting natural resources
- Providing financial assistance
- Developing context-specific strategies.

To assist with decision-making, the Community-based Adaptation (CBA) framework is proposed for creating inclusive governance. The CBA framework engages a range of stakeholders directly with local or district government and national coordinating bodies, and facilitates participatory planning, monitoring and implementation of adaptation activities. Seven criteria are suggested for the prioritisation of adaptation technologies: (i) the extent to which the technology maintains or strengthens biological diversity and is environmentally sustainable; (ii) the extent to which the technology facilitates access to information systems and awareness of climate change information; (iii) whether the technology supports water, carbon and nutrient cycles and enables stable and/or increased productivity; (iv) income-generating potential, cost-benefit analysis and contribution to improved equity; (v) respect for cultural diversity and facilitation of inter-cultural exchange; (vi) potential for integration into regional and national policies and upscaling; and (vii) the extent to which the technology builds formal and informal institutions and social networks.

Finally, this guidebook makes the following recommendations for practitioners and policy makers:

- There is an urgent need for improved climate modelling and forecasting that can provide a basis for informed decision-making and the implementation of adaptation strategies. This should include traditional knowledge
- Information is also required to better understand the behaviour of plants, animals, pests and diseases as they react to climate change
- Potential changes in economic and social systems in the future under different climate scenarios should also be investigated so that the implications of adaptation strategy and planning choices are better understood
- It is important to secure effective flows of information through appropriate dissemination channels. This is vital for building adaptive capacity and decision-making processes
- Improved analysis of adaptation technologies is required to show how they can contribute to building adaptive capacity and resilience in the agriculture sector. This information needs to be compiled and disseminated for a range of stakeholders from local to national levels
- Relationships between policy makers, researchers and communities should be built so that technologies and planning processes are developed in partnership, responding to producers' needs and integrating their knowledge.

1. Introduction and Outline of the Guidebook

This guidebook supports developing countries to select adaptation technologies and practices in their agriculture sectors. It shares the definitions set by the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (IPCC WG II, 2007) on: (i) the Agriculture Sector, which includes food crops, pastures and livestock, industrial crops and biofuels, forestry, aquaculture and fisheries, and small-holder and subsistence agriculturalists and artisanal fishers; and on (ii) Climate Change Adaptation, which includes initiatives and measures to reduce the vulnerability of human and natural systems facing actual and/or expected effects of climate change. The technologies included in the guidebook are relevant primarily to the crop, livestock, and forestry sectors and are particularly focused on small-holder producers who are considered to be the most vulnerable to climate change.

Agricultural producers have been modifying their practices to cope with climate variability and change for centuries. However, climate change is now threatening their livelihoods from increasingly unpredictable, frequent and intense climate extremes such as droughts, floods and frosts. Some efforts have been made to document these experiences and this information is mainly available from internet-based platforms, along with some specialised publications. A wide range of literature is also available on projects and programmes implemented by governments, non-governmental organisations (NGOs), and other actors. This guidebook has been developed based on information representing this range of experiences, to provide a balanced assessment of adaptation technologies.

The target audience of this guidebook is broad and includes individuals in government institutions, NGOs, and the private sector. The guidebook is intended to provide an essential source, but not an exhaustive set, of key information on climate change adaptation in the agriculture sector. It is concise and self-explanatory, with clear referencing so that the target audience can easily access and understand the information and concepts presented without prior extensive knowledge of other reading materials or the topics concerned. For this reason, essential technical terms specific to the agriculture sector are explained in the glossary.

The outline of the guidebook is as follows.

Chapter 2 explains key concepts including agriculture sector, livelihoods, climate change, ecosystem, climate change impacts on ecosystems, agriculture and social impacts (food security, poverty, water, displacement and security), climate change vulnerability and adaptation, disaster risk management, technology (hardware, software and orgware) and biotechnology. It also explores the linkages between rural livelihoods, agriculture, biodiversity, climate change, risk, development and adaptation technologies. It describes the four levels at which climate change adaptation technologies can be implemented within the national context: individual and household; community and local government; intermediate-level institutions; as well as national government and international institutions.

Chapter 3 describes the process for adaptation decision-making and prioritisation of adaptation technologies. Firstly, it explains the process for vulnerability and risk assessment. Features of this process and suggested methodologies are also included. Secondly, options for adaptation technologies are

explored by describing two scenarios of strategies: when building resilience to possible future climate change impacts and an increase of diversity is recommended, and when current vulnerabilities are being addressed and impact-specific measures can be implemented. Thirdly, a process of adaptation strategy selection and decision-making is suggested. It includes the features of a National Adaptation Strategy, the guiding principles for adaptation technology selection and a three-phase decision-making process suggested. The important role of culture is also discussed. Finally, Chapter 3 provides key criteria for reviewing the effectiveness of the adaptation measures and actions.

Chapter 4 presents 22 adaptation technologies suitable for the agriculture sector in developing countries. Research and development processes play a critical role in the emergence, testing and dissemination of new adaptation technologies. This guidebook focuses on existing technologies and is non-exhaustive. As such, some adaptation technologies that are important for certain regions and to certain climate change impacts may not be covered in this guidebook. They are grouped into seven categories: (i) planning for climate variability and change, (ii) sustainable water use and management, (iii) soil management, (iv) sustainable crop management, (v) sustainable livestock management, (vi) sustainable farming systems, and (vii) capacity building and stakeholder organisation. Table 1.1 lists the technologies covered in this guidebook.

Table 1.1 Overview of Technologies Covered in the Guidebook

Technology Categories	Technologies
Planning for Climate Change and Variability	1. National Climate Change Monitoring System
	2. Seasonal to Interannual Prediction
	3. Decentralised Community-run Early Warning Systems
	4. Climate Insurance
Sustainable Water Use and Management	1. Sprinkler and Dripping Irrigation
	2. Fog Harvesting
	3. Rainwater Harvesting
Soil Management	1. Slow-forming Terraces
	2. Conservation Tillage
	3. Integrated Soil Nutrient Management
Sustainable Crop Management	1. Crop Diversification and New varieties
	2. New Varieties through Biotechnology
	3. Ecological Pest Management
	4. Seed and Grain Storage
Sustainable Livestock Management	1. Selective Breeding via Controlled Mating
	2. Livestock Disease Management

Contd...

Sustainable Farming Systems	1. Mixed Farming
	2. Agro-forestry
Capacity Building and Stakeholder Organisation	1. Farmer Field Schools
	2. Community Extension Agents
	3. Forest User Groups
	4. Water User Associations

For each technology, the following is covered: (i) definition and description (ii) how the technology contributes to climate change adaptation (iii) other benefits or limitations (iv) knowledge monitoring, institutional, organisational, cost and financial requirements for implementation, (v) implementation opportunities and barriers, and (vi) a real example of its application from Latin America, Asia, Africa or Eastern Europe. Boxes provide more details on some issues and invite the readers to explore additional sources of information.

Chapter 5 is devoted to conclusions and sets out recommendations.

The **references** used in the guidebook are presented alongside a **glossary** of technical terms and a list of recommended sources for additional information.

2. Background

2.1 Key Concepts

Agriculture Sector

This guidebook adopts the Intergovernmental Panel on Climate Change's (IPCC) definition of the agriculture sector. The scope of the agriculture sector, as defined in the IPCC Fourth Assessment Report on Climate Change (IPCC WG II, 2007), includes food crops, pastures and livestock, industrial crops and biofuels, forestry (commercial forests), aquaculture and fisheries, small-holder and subsistence agriculturalists, and artisanal fishers.

Agriculture is a key sector for providing economic and social development in developing countries because most of the world's poor people depend on agricultural production as a main source of household income (FAO, 1995). Over 60 per cent of Africans depend directly on agriculture for their livelihoods (FAO, 2003). More than 75 per cent of South Asia's poor people live in rural areas and depend on rain-fed agriculture, livestock and forests for subsistence (Sapkota, 2010). In Latin America, the percentage of populations engaged in agriculture has been much lower, the sector is still crucial for around 70 per cent of the rural poor (Muchnik et al., 1997).

The 2008 World Bank Report *Agriculture for Development* highlights the relevance of agriculture¹ to development. The report also demonstrates how, alongside other sectors, agriculture can contribute to faster economic growth, poverty reduction and environmental sustainability. The report states that agriculture contributes directly to development in three ways:

- As an economic activity not only because it is the source of income for the majority of the rural poor but also because it can be a source of national growth, a provider of opportunities for private investment and a driver of agriculture-related industries;
- As a source of livelihood for an estimated 86 per cent of rural people globally, most of whom are poor. In poor rural regions a high priority is therefore to mobilise agriculture for poverty reduction; and
- As a provider of environmental services.

Although bad agricultural practices can contribute to water depletion, agro-chemical pollution, soil exhaustion and global climate change, appropriate techniques can promote carbon sequestration on degraded land, watershed management and biodiversity conservation (World Bank, 2008; 2-4).

Improvements in agricultural production have shown to lead to poverty reduction in all contexts. Cross-country estimates show that Gross Domestic Product (GDP) growth from agriculture is at least twice as effective in reducing poverty as GDP growth originating from any other sector (World Bank, 2008; 6). However, the way agriculture contributes to development varies across countries depending on the extent it is a source of economic growth and what percentage of the rural poor are engaged in agricultural activities:

- Agriculture-based countries (agriculture generates on average 29 per cent of GDP and employs 5 per cent of the labour force);
- Transforming countries (agriculture contributes only 7 per cent to GDP growth, but 82 per cent of all poor live in rural areas); and
- Urbanised countries (agriculture contributes only 5 per cent on average to GDP and although poverty is mostly urban, 45 per cent of poor live in rural areas) (World Bank 2008, 4).

Poverty reduction can also be achieved through the agriculture sector by helping small-holders secure the right to food. Today, approximately one billion people are undernourished (FAO, 2009). The vast majority of these undernourishments are connected to food provision: three quarters of such cases are in rural communities (IFAD, 2002) where agriculture provides a livelihood for nearly 90 per cent of people (World Bank, 2008). Small-scale food providers include (ETC Group, 2009):

- 190 million pastoralists who raise livestock
- 100 million artisanal fishers or people who are engaged in processing half of all fish caught for human consumption
- 800 million people who are involved in urban farming, 200 million of which are producing for urban markets
- At least 410 million people who derive much of their food and livelihoods from forests.

Smallholders are often negatively affected by unfavourable market conditions. They sell their goods at low prices but are then forced to buy at high prices during periods of scarcity. Dependence on expensive inputs and technology packages and along with lack of financial and technical support from public and private sectors also contribute to increasing the vulnerability of the environment in which many small-holders still find themselves.

Agriculture is a key sector for tackling hunger and reducing poverty, in particular in developing countries. As agriculture is directly affected by climate change, adaptation strategies, technologies and practices are becoming increasingly important issues for promoting development.

Livelihoods

Livelihoods are the full range of activities that people practice to make a living and have a good life. This relates not only to how people earn their main source of employment or income, but also about all the different activities and choices within the household and community which provide food, health, income, shelter and other tangible and intangible benefits, such as comfort, safety, respect and fulfilment. Livelihood activities can include agricultural production (such as crops, vegetables, livestock, and fish) for home consumption or for sale of produce (such as grains, vegetables, milk, eggs, and fish); non-agricultural home production such as tailoring, pottery, and food processing; wage derived locally or by migrating to another area to work, for example, as a rickshaw driver, in a factory or in construction; managing or harvesting forest products, such as timber extraction or beekeeping.

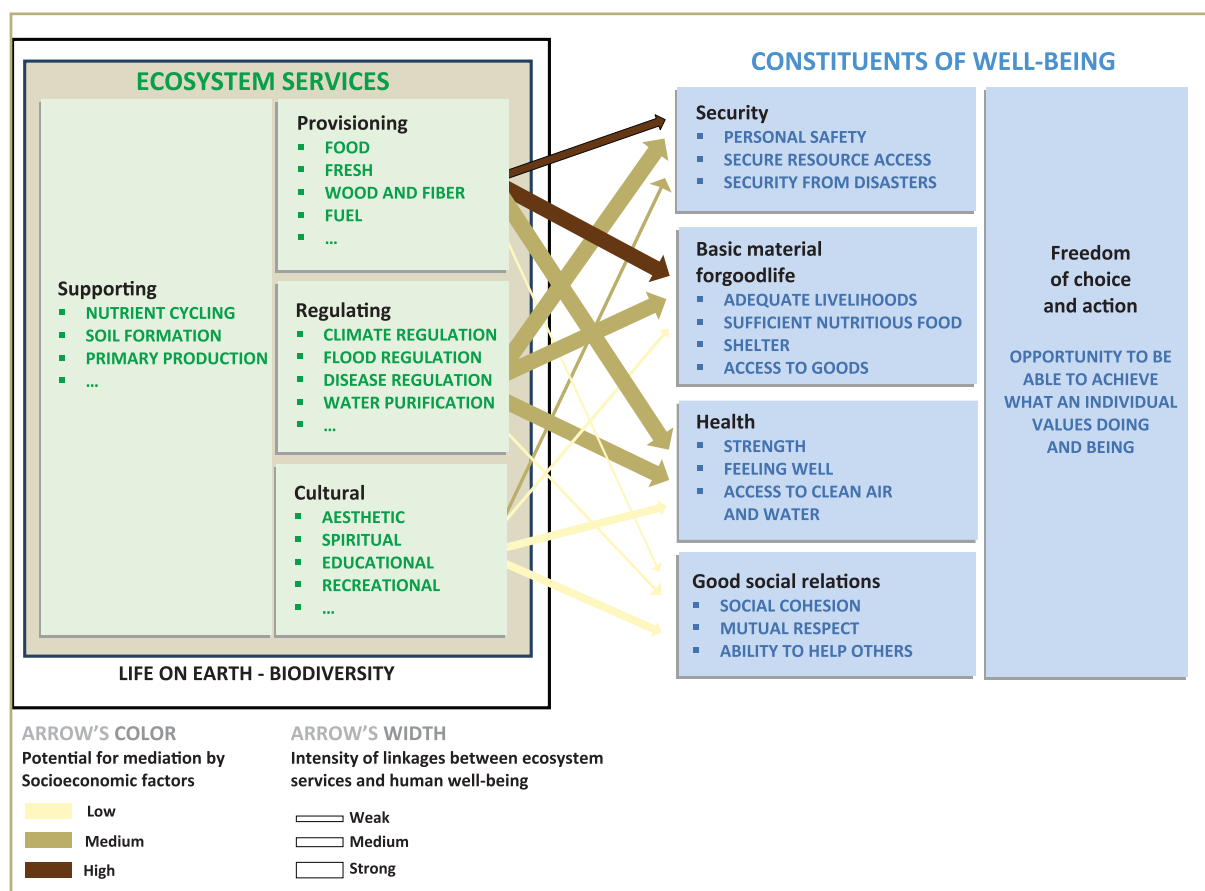
Livelihoods can consist of any number of different activities – some playing a significant role and some serving at a minor level. Livelihoods are fragile if they are based on a limited range of activities and put households at risk when one of those activities fails (for example, a job is lost or a harvest fails). Livelihoods are also fragile if they are weak or unprotected from possible threats, for example, livestock quality is poor and unvaccinated, making them vulnerable to disease; or soil and water conservation techniques

are not used on farmland, leaving it exposed to erosion and drought. It is the diversity in livelihoods at the household and community scales that builds resilience.

Ecosystem

According to the Convention on Biological Diversity (CBD), an ecosystem is “a dynamic unit of natural resources consisting of plant, animal and micro-organism communities and the non-living environments.” Ecosystems exist on a variety of scales. An example of a small-scale ecosystem is a pond, whereas a tropical rainforest is a very large ecosystem. Ecosystems provide a range of services to human beings such as the supply of food, energy and fuel, water purification, soil formation, and recreational and spiritual benefits (Figure 2.1).

Figure 2.1 Linkages between Ecosystem Services and Human Well-being.



Source: WRI Millennium Ecosystem Assessment (2005)

The structure of the world's ecosystems has been significantly transformed by humankind through a range of actions, in particular through the conversion of land to meet the demand for food, fresh water, timber, fibre, and fuel. Today, approximately one quarter of the earth's surface is used for cultivated agriculture (WRI, 2005). An agricultural ecosystem (or agro-ecosystem) is a controlled unit designed and managed by humans for production of food (crops and livestock), fuel and fibre. The sustainable productivity of agricultural ecosystems is dependent on a balance occurring between the range of species, organisms and non-living matter, primarily between crops, animals, soil, water and the atmosphere. Conserving

biodiversity within agricultural ecosystems is therefore indispensable for sustaining crop production, food security and livelihoods (Ensor, 2009).

Climate Change

Climate change: a change in the climate that persists for decades or longer, arising from either natural causes or human activity (IPCC WG II, 2007; 30).

It is now considered 'unequivocal' that the global climate is changing, principally as a result of burning fossil fuels and agriculture related land use change which contributes to the greenhouse effect. According to the IPCC Fourth Assessment Report (IPCC WG II, 2007), the temperature of the earth's surface is expected to increase between 2 and 5 degrees Celsius (°C) over the next century, assuming greenhouse gas emissions continue to rise at current rates. This is gradually warming the planet and having a number of knock-on effects in terms of changing rainfall patterns, rising sea levels, and more unpredictable weather events. Climate change is expected to lead to more frequent, more extreme or more unpredictable occurrence of existing natural hazards (such as temporal distribution of rainfall, floods, droughts, hurricanes, and cyclones). It can also result in the emergence of new hazards which did not occur previously in a particular locality, such as new types of pest outbreak or disease resulting from rising temperature. Gradual changes in the climate and natural environment are putting pressures on livelihoods which are dependent on natural resources.

The precise implications of climate change remain unclear: predictions of rainfall rates, amounts and patterns, the likely frequency of extreme weather events, and regional changes in weather patterns cannot be made with certainty. Regional climate models are becoming more accurate, but unfortunately too little effort has been invested into research on regional climate models in developing countries and in low latitude regions. While the highest emission scenario in the IPCC's Fourth Assessment Report (IPCC WG II, 2007) produces a most likely average temperature increase of 4°C by the end of the 21st century, it is also possible that the increase might be as high as 6.4°C or as low as 2.4°C (Meehl et al, 2007). Currently, the impact of uncertainty can be seen most clearly in the failure of climate models to provide good agreement at the regional scale, and in particular on future levels of precipitation. In West Africa, for example, the impact of climate change on rainfall is unclear. Climate models sometimes fail to agree as to whether precipitation will increase or decrease in any season (Christensen et al., 2007). Climate change, then, provides a particular challenge: we know that change is coming, and we can even know the direction of change in many cases, but our ability to foresee that change depends on a number of factors. The degree of confidence with which predictions can be made depends on how far into the future we look, what region we are in, whether a local or national prediction is needed, whether we are concerned with temperature, precipitation or extreme events all have an impact on the degree of confidence with which predictions can be made. We need to differentiate climate change projections for short-term (10-20 years) medium term (20-40 years) and long term (>40 years) scenarios, as this will have different impacts on adaptation decisions.

Climate change contributes to vulnerability through creating greater uncertainty and unpredictability in the environment within which poor people live and build their livelihoods. Importantly, it is changing the prediction schemes or prediction rules, i.e. old knowledge is no longer of the same use as it used to be. For the majority of weather related hazards and stresses there has tended to be a considerable amount of knowledge and certainty about their characteristics based on historical experience (for example, the timing of monsoon rains, patterns of cyclones, seasons of heavy frost probability), climate change is rendering it

much more difficult to predict future climate characteristics using historical evidence. At a global level and for the long-term projections (>40 years) climate change predictions vary widely, depending on assumptions about future trends in industrialisation and consumption patterns (resulting in increasing CO₂ emissions) as opposed to more optimistic assumptions about the adoption of cleaner technologies and stronger policy lines on emission reduction (CO₂ stabilisation). Predictions of impacts at the national and local levels are extremely challenging, due to the range of factors and feedback loops that could affect future climate, and the inadequacy of capacity to gather and analyse data for all regions. At all scales, rainfall – which is critical to agriculture – is harder to predict than changes in temperature.

Over half a billion people are at extreme risk to the impacts of climate change, and six in ten people are vulnerable in a physical and socio-economic sense (GHF, 2009; 3). Poor and remote communities are especially vulnerable to climate change as they tend to be unable (or less able) to access relevant information about possible changes in climate, or warnings of unpredictable weather events. Such communities have tended to rely on traditional indicators of climate and weather patterns, such as the appearance of migratory birds, or the flowering of certain trees. As both weather patterns and the traditional indicators become increasingly unreliable, farmers are highly vulnerable to production losses which might result from unpredicted weather events. For example, heavy rains occurring shortly after planting wash away seedlings or unexpected hailstorms destroy ripening crops. Alternative sources of information, such as reports from meteorological offices, are often unavailable to such communities due to poor or inexistent communication channels, or a failure to focus on the needs of the poorest.

Climate Change Impacts

Ecosystems

The ability of ecosystems to naturally adapt to changes in climate is likely to be severely reduced over the next century. This is due to unprecedented combinations in climatic events such as severe flooding and drought, ocean acidification, and the emergence of new pests. This also includes land-use change and the over-exploitation of natural resources due to human activities (IPCC WG II, 2007; 213).

Agriculture

Agricultural activity is highly sensitive to climate change, largely because it depends on biodiversity and environmental conditions. Sufficient freshwater supplies, fertile soil, the right balance of predators and pollinators, air temperature and average weather conditions all contribute to maintaining agricultural productivity. As agriculture depends directly on environmental conditions, climate change impacts on agriculture are becoming increasingly evident. Changes in rainfall cycles are impacting on agricultural yields as water availability is decreasing in already arid zones and water excesses (floods) are being experienced in other areas. A warmer climate with changes in patterns of drought or increased precipitation, will affect agricultural production in large parts of Latin America, Asia and Africa. Some agricultural land may no longer be cultivatable, growing seasons will change and productivity will decrease, particularly in Africa. In the middle and high latitudes of the northern hemisphere, longer growing seasons could have a positive effect on crop yields (where rainfall is not negatively affected).

Small-scale farmers are among the first to feel the impacts of climate change because of their greater dependence on the natural environment. Extreme climate variability (drought, floods and frost) can destroy the economies and welfare of poor rural families because they lack technologies, social protection mechanisms (such as benefits, insurance and savings) and adequate protection for their crops and animals.

Table 2.1 Climate Change Impacts on Agriculture

Climate Phenomena	Impacts on Agriculture	Probability
In most terrestrial areas, days and nights will be warmer, less frequently cold and more frequently very warm	Better harvest in cold environments; worse in warm environments; insect pests more frequent	Almost certain
More frequent heat waves and warm periods	Impoverishment of the crops in warmer regions due to heat stress; increased risk of uncontrolled wildfires. In currently cold mountain climates, yield increases	Very likely
More frequent intense precipitation events in most regions	Damage to crops, soil erosion, inability to cultivate the land due to waterlogging	Very likely
Increase in areas affected by drought	Lower yields, crop damage and even crop failure; major losses of livestock; increased risk of uncontrolled wildfires	Likely
Increased intensity of tropical cyclones	Damage to crops, uprooting of trees, damage to coral reefs	Likely

Source: based on IPCC WG II, 2007; 13

Changing amounts and patterns of precipitation is already causing farmers to struggle. It is very likely that precipitation in high latitudes will increase and it is likely that in most sub-tropical regions precipitation will decrease in line with recently observed trends; with a high degree of confidence it is projected that by mid-century, annual river runoff and water availability will increase at high latitudes (and in some wet tropical areas) and decrease in some dry regions at mid-latitudes and in the tropics (IPCC WG II, 2007; 8-9).

Food Security

Together with local overpopulation and poor land and water management, climate change is responsible for causing hunger and malnutrition for some 45 million people worldwide as a result of reduced yields of cereals, fruits, vegetables, livestock and dairy, and cash crops like cotton and fish (GHF, 2009; 24). Poor people, especially children, the elderly and the ill, suffer from hunger and malnutrition when agricultural yields, livestock and fish supplies decline. Climate change is affecting the ability of subsistence farmers to produce sufficient food by creating less favourable growth conditions. Many do not have enough crop production to feed their families and the shortfall may force them to buy food when prices are high (GHF, 2009; 23).

Poverty

Weather-related disasters and desertification destroy livelihoods of the poor when income depends on agriculture (mainly if they are subsistence farmers), tourism and fishing. Poor people have the least assets and savings to rely on in the event of a shock (GHF, 2009; 34). Climate change is expected to reduce the earning potential of future generations because it decreases current family income and increases the number of hungry children and child labour (reducing educational opportunities) (GHF, 2009; 36).

In addition, many people could be pushed into poverty due to the incapacity to recover from climate change disasters.

Water

Growing evidence suggests that changes in the hydrological cycles can bring longer droughts and more intense rains making wet regions even wetter and arid areas drier (GHF, 2009; 40). Changes in rainfall and the disappearance of glaciers will result in a considerable reduction of water quantity and quality for human consumption and farming. This in turn will affect agricultural production and food security. Rising sea levels cause saltwater intrusion into ground water and fresh water streams and warmer water temperatures also accelerate water pollution (GHF, 2009; 40). Water scarcity is projected to become one of the main causes of social conflict in the developing world. Poor people in rural areas will suffer most from an increased lack of water, as they already travel considerable distances to access this basic human necessity.

Displacement (involuntarily, either permanent or temporary)

It is difficult to isolate the influence of climate change on displacement because of other contributing factors such as poverty, population growth and employment options. However, it is evident that climate change is contributing to the displacement and migration of populations through weather-related disasters which destroy homes and habitats and through environmental effects such as desertification and rising sea levels (GHF, 2009; 46).

Security

Poor people are the most vulnerable to experience conflict over resources because they tend to reside in areas where natural resources are scarce and institutions are weak. Climate change intensifies negative environmental trends like desertification, soil salinisation and water scarcity contribute to resource scarcity (including supply of food, fresh water for people and livestock, agricultural produce). It leads to more fierce competition for food, land and water and creates situations with a propensity for resulting in conflicts (GHF, 2009; 53).

Development Assistance

Climate change significantly impacts the international community's development assistance and humanitarian relief efforts (GHF, 2009; 66). Given that climate change affects poor people most, it seriously threatens the achievement of the Millennium Development Goals (MDGs)². Overall, climate extremes (heat waves, drought, floods, torrential rainfall) are particularly hazardous to crop production, not only at the local level but also over large areas, therefore affecting global food prices which directly impacts on poor people.

Climate Change Vulnerability

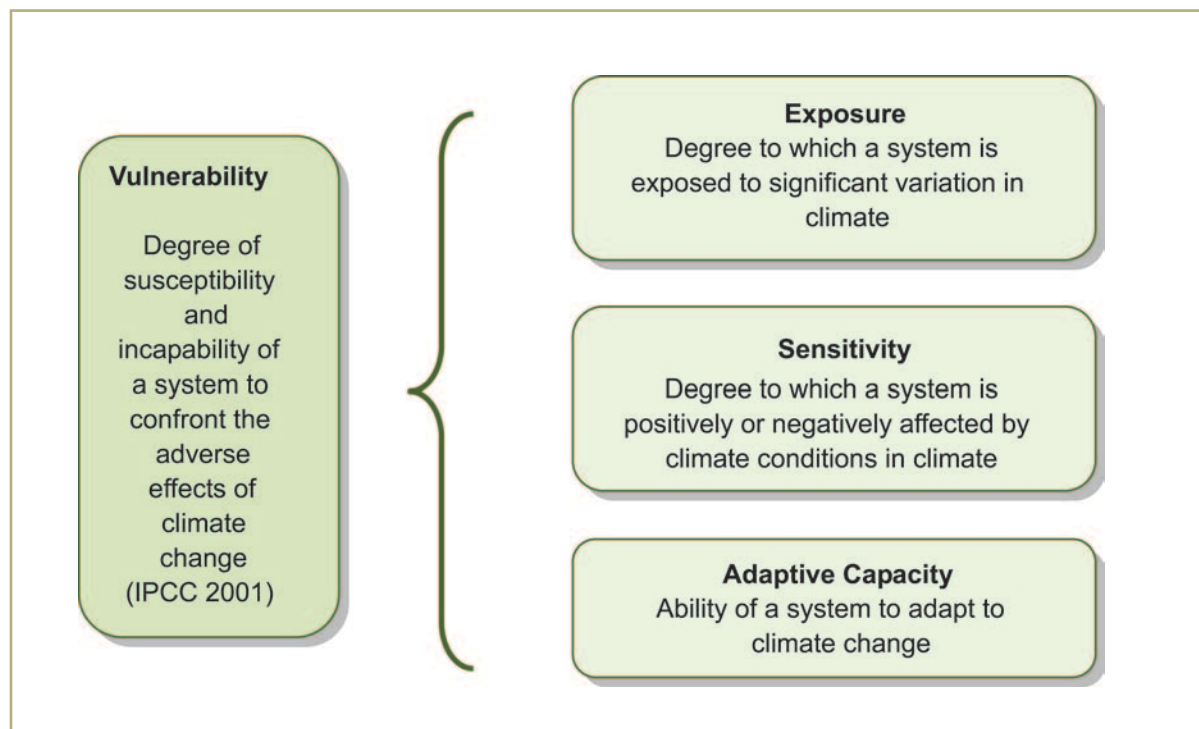
The vulnerability to climate change of a sector or the livelihoods of families can be divided into three aspects (see Figure 2.2):

- The exposure to climate change, i.e. how much the climate is expected to change and in what aspects. This information generally comes from the climate models, which indicate not just the possible changes in temperature and rainfall but also the number of expected days with extreme high or low temperatures and in some cases differences in the distribution of rainfall. In coastal areas this may be the increase in sea-level rise that may be expected.

- The sensitivity to climate change is the degree to which livelihoods or productive activities are likely to be affected by climate change. Climate may change but for urban populations this may not greatly affect their livelihoods, while for farmers changes may be of considerable importance. Sea-level rise is extremely important for a coastal community that lives along an estuary but of little importance to one that is on a cliff. Nevertheless, the sensitivity can be seriously affected by the level of resources that a family has at their disposal; for rural families, even if all depend on agriculture, the sensitivity to climate change is generally much greater for those with more marginal livelihoods.
- The adaptive capacity of a family or sector is also of importance. The current livelihood of a family may be highly exposed to climate change, but if they have the capacity to adapt their overall vulnerability may not be high. If a family accustomed to growing maize, has experience in producing sorghum in dry years, they may be better prepared to make a more permanent change if conditions become drier. Again, the capacity to adapt varies considerably between families even within the same community. The most important characteristics for the capacity to adapt is human knowledge and access to social institutions where this knowledge can be shared.

This framework has been used to understand the nature of vulnerability of rural families. It can help support organisations identify and prioritise in which to invest to help decrease the sensitivity or increase the adaptive capacity of families and their organisations (Hahn et al 2009).

Figure 2.2 Vulnerability to Climate Change Divided into its Components of Exposure, Sensitivity and Adaptive Capacity



Source: based on IPCC, 2001

Climate Change Adaptation

Climate change adaptation: an adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities (IPCC WG II, 2007).

Adaptation can prevent future risks, it can reduce present adverse effects and it can refer to individual or collective action (GHF, 2009; 69). Climate change in many cases will lead to increased climatic variability and more extreme climatic events which will directly affect agriculture. Resilience to variation and the unexpected, and the capacity to adapt to a changing world are therefore cornerstones of adaptation.

Adaptive capacity is defined as “the ability of a system [human or natural] to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences” (IPCC, 2001). Adaptive capacity of individuals, households and communities is shaped by their access to and control over natural, human, social, physical and financial resources (CARE 2010).

Table 2.2 Examples of Resources Affecting Adaptive Capacity

Human	Knowledge of climate risks, conservation agriculture skills, good health to enable labour
Social	Women’s savings and loans groups, farmer-based organisations, traditional welfare and social support institutions
Physical	Irrigation infrastructure, seed and grain storage facilities
Natural	Reliable water resources, productive land, vegetation and trees
Financial	Micro-insurance, diversified income sources

Source: CARE, 2010; 11

Individual and social factors determine vulnerability and capacity to adapt to the effects of climate change (GHF, 2009; 3). Adaptation implies capacity building (including skills, technologies, building stronger institutions and promoting social equity) and strengthening livelihoods for poverty reduction. Climate change adaptation needs to take account of uncertainty by ensuring that livelihoods (and therefore also ecosystems) maintain and enhance the ability to ride out or respond to unexpected events. Addressing the risks and vulnerabilities of the poor who live in insecure places and need to build their resilience to cope with climatic fluctuations are among the most important challenges in adapting to increasing climate variability and climate change (FAO, 2007; 17).

People whose livelihoods depend on agriculture have developed ways to cope with climate variability autonomously but the current speed of climate change will modify known variability patterns to the extent that people will be confronted with situations they are not equipped to handle (FAO, 2008; 3). Anticipatory and planned adaptation is an immediate concern but vulnerabilities are mostly local and, thus, adaptation should be highly location specific (idem). In this sense, adaptation needs to be understood as a process,

through which communities gain access to resources, information and the ability to shape their lives and livelihoods as the environment changes around them. The ongoing nature of climate change and the inherent uncertainty in weather and climate projections necessitate an approach that empowers communities. This includes building their capacities and opportunities to play an informed role in decision-making over the technologies and strategies that are appropriate to their needs, over which resources are needed and available, and when (Ensor and Berger, 2009a). If there is high certainty around a future climate scenario, impact-specific measures can be implemented, such as constructing flood-proof housing. If certainty is low, implementing robust adaptation – or so-called ‘no-regret’ – measures will be more appropriate. These generate net social benefits under all future climate change scenarios, focusing on reducing vulnerability while strengthening communities’ capacity to adapt through sustainable development (Ensor, 2009).

Additionally, there are development processes that constitute mal-adaptation because they increase vulnerability. Examples of these include planning without considering risks, badly designed or executed projects, location of population centres or productive infrastructure in disaster-prone terrain, food insecurity, lack of basic services (health, water, sewage, education), limited access to shelter or unsafe housing, poverty that limits the ability to recover from a disaster, insufficient social protection mechanisms, limited information about the risks, and insufficient participation.

Disaster Risk Management

Disaster Risk Management (DRM) is the process of adoption of policies, strategies and practices oriented to reduce the risk level or to minimise its effects. There are three types of DRM: (i) prospective, oriented to avoid new conditions of risk, (ii) corrective, reducing existing risks, and (iii) reactive, oriented to the preparation and response to disasters. In agriculture, DRM programmes have been implemented to limit the impacts on production, thus reducing persistent food shortages and preventing widespread famines. Programmes include early warning systems, infrastructure development, social protection measures, risk awareness and assessment, education and training, and environmental management (IDS, 2009: 13).

Climate change is leading to more frequent hazards and stresses (such as droughts and floods), which require similar actions to those outlined in the disaster management approach. Furthermore, 10 per cent of deaths related to climate change are due to disasters (GHF, 2009). There is therefore a general consensus on the need to integrate DRM within climate change adaptation approaches (Venton and La Trobe 2008: 4).

Technology

Technology is a vital contributor to people’s livelihoods. It includes physical infrastructure, machinery and equipment (hardware), knowledge and skills (software) and the capacity to organise and use all of these (orgware); but also the biological technology with which farmers produce. Biological technology complemented with advances in crop nutrition and crop protection (such as pesticides), equipment (hardware) and knowledge (software), have been the primary driver of increased productivity in agriculture.

Based on this, it is important to have a people-focused or people-centred definition of technology. Improvements to technologies can have many positive impacts for poor people’s livelihoods. They can lower costs, for example labour saving devices such as a draught plough reduce the labour costs required with hand tools. They can improve quality and output, e.g. improved seeds or cultivation techniques. They can also help people to reach new markets, for example mobile phone or the internet providing access to market information. Technologies can also be employed to reduce risks. They can protect people or assets from potential hazards, for example raised housing or dams can offer protection from floods, and

vaccinations can protect people and animals from health hazards. They can also be employed to enhance the early warning of hazards, and used in response activities to reduce hazard impact, for example rescue boats and life jackets.

This guidebook defines the term technology in a broad sense, including hardware, software and orgware. These types of technologies complement the biological technology that producers manage.

- **Hard technologies (hardware)** refer to the tangible aspects such as the manufactured objects, the machinery, the equipment and tools required to produce goods or services. For example, a sprinkler irrigation system
- **Soft technologies (software)** refer to the processes associated with the production and use of the hardware, including know-how (such as manuals and skills), experiences and practices (such as agricultural, management, cooking and behavioural practices). Soft technologies also encompass elements of awareness-raising, including education and training. For example, capacity building in animal health
- **Organisational technologies (orgware)** refer to the institutional framework, or organisation, involved in the adoption and diffusion process of a new technology. Orgware relates to ownership and institutional arrangements of the community/organisation where the technology will be used. An example is the establishment of Water User Boards.

Appropriate technologies can help farmers and other producers to overcome the physical and environmental constraints of exposed areas, improve productivity and incomes, and help them to adapt to changes in the climate. Appropriate technologies are those which can be managed and maintained by them over the long term, and which integrate environmental, economic and social sustainability principles. Whether modern or traditional, local or introduced, if producers have access to a wider choice of appropriate technology options, they are able to innovate and improve their practices. The capacity to differentiate and decide between technologies is also necessary.

Biotechnology

Biotechnology has been the fundamental basis for the development of agriculture across the world. It has its origins in the first selection of wild seeds to sow higher yielding plants and the first animals that were domesticated to meet human needs. Over the past century the development of biotechnology has been taken over by dedicated scientific research resulting in the capacity to manipulate the genes that determine the nature of the plants and animals farmers cultivate and care for.

Biotechnology is not just creating transgenic organisms, which have had DNA from another organism introduced into their DNA. This is possibly the least common form of biotechnology. Biotechnology's greatest relevance so far has been in producing pest and disease-resistant plants, the impacts of which are hotly debated. A second form of genetic modification is suppressing gene expression in the actual plant genome. This may lead to characteristics of improved drought resistance, vitamin production or similar traits. Finally, biotechnology can be used to screen materials in traditional breeding programmes (also genetic modification) more rapidly and include a wider range of materials to know which have the genetic characteristics of pest resistance that exist naturally in the population but are difficult to separate out and combine with productive traits. This is probably the most common use of biotechnology – to speed up the processes of 'traditional' plant breeding.

The Cassava mosaic virus-resistant plants released in East Africa have saved possibly millions from starvation. These resistant plants were identified through biotechnology, but are not Genetically Modified Organisms (GMOs). Cassava Brown Streak Virus is currently causing similar problems and biotechnology is being used to accelerate the process of identifying naturally resistant materials. Other kinds of biological research include the identification and production of pheromones to trap tsetse flies or propagating naturally occurring viruses that controls armyworms in Africa. None of these materials have associated intellectual property (IP) that restrict access to poor farmers, as they were developed by public institutes. Nevertheless, the overall shift of funding of agronomic research from the public to the private sector has led to commercial companies being the primary developers of the new biotechnology and genetically modified crops. The commercial development of such technology means that small farmers and developing countries are often not their primary interest. It also means access to such technologies depends on the conditions laid down by the company. The potential and the limitations of biotechnology are further discussed in Chapter 4.

2.2 Agricultural Production Systems

Agricultural production systems have evolved over time and in diverse ways. Their evolution has been in response to a range of interacting factors related to production, consumption, trade and politics. Agricultural production systems are embedded in economic, social, environmental, political and cultural contexts which must be clearly understood before potential options for adaptation to climate change can be explored. A multitude of systems exists worldwide which incorporate polycultures, monocultures, aquaculture, agro-forestry, and livestock among others (Dixon et al, 2001). Three broad categories of agricultural production existing today include:

Traditional System

The traditional system includes indigenous forms of agriculture oriented towards subsistence or small-scale commercial farming. Globally, food provision is dominated by small-scale agriculture (IAAST, 2009). An estimated 70 per cent of the global population (nearly 4.7 billion people) are fed with food produced locally, mostly by small-scale farming, fishing or herding (ETC Group, 2009). Small-scale farmers produce almost 80 per cent of food on regional markets in Africa and Asia (Vermeulen, 2010). In Latin America the contribution of traditional small-scale (peasant) farming to food supply in the region is also significant. National data from Brazil, Bolivia and Ecuador shows that 60 to 80 per cent of staple foods and over 50 per cent of dairy and meat products originate from family farms (Schejtman, 2010). Eighty-five per cent of the world's farms are less than 2 hectares, worked by families and indigenous peoples. Strengthening the livelihoods of rural populations is intrinsically linked to poverty reduction efforts and is a key area to focus climate change adaptation strategies in the agriculture sector.

This system is implemented using basic and locally available inputs, such as family labour, native livestock breeds and plant species, and organic fertiliser. Traditional knowledge around farming practices is highly important and usually passed on from generation to generation with improvements and adaptations taking place according to changes in local conditions. It is widely accepted that indigenous knowledge is a powerful resource in its own right and complementary to knowledge available from western scientific sources. One of the salient features of the traditional system is a high level of biodiversity. Biodiverse farms bring together key organisms that, in combination, can promote and enhance the ecosystem services that are important to the performance of the agro-ecosystems. While a huge variety of these farms exist across the world, they share common features, as outlined in Box 2.1.

Box 2.1 Common Features of Biodiverse Farms

- They combine species and structural diversity in time and space through both vertical and horizontal organisation of crops
- The higher biodiversity of plants, microbes, and animals inherent to these systems supports production of crops and stock, and also mediates a reasonable degree of biological recycling of nutrients
- They exploit the full range of micro-environments, which differ in soil, water, temperature, altitude, slope, isolation and fertility within a field or region
- They maintain cycles of materials and wastes through effective recycling practices
- They rely on biological interdependencies that provide some level of biological pest suppression
- They rely on local resources plus human and animal energy, using little modern technology
- They rely on local varieties of crops and incorporate wild plants and animals. Production is usually for local consumption.

Source: Altieri and Koohafkan, 2008

Using inventive self-reliance, experiential knowledge, and locally available resources, some traditional farmers have been able to develop farming systems with sustained yields (Harwood, 1979). Practices often integrate careful management of natural resources with intimate local knowledge of climate, fauna and flora and a spiritual or religious relationship with the earth. However, some local farming systems do not function viably under changing internal and external pressures. Examples of traditional agricultural practices include crop diversification and rotation, terracing, and minimal tillage (Grigg, 1974; Brush, 1986; Richards, 1985). Practices also include shifting cultivation and slash and burn practices whose sustainability has come under pressure with increasing population.

Figure 2.3 Traditional Agricultural Practices



(1) Native potato producers in the Peruvian Andes

Source: Practical Action



(2) Boys herding and tending goats in Kenya
Source: John Young, Practical Action

The traditional system is typically carried out on marginal land with basic technology. Productivity levels are generally low. However, research shows that small farms can be much more productive than large farms if total output is taken into account rather than yield from a single crop (IFAD, 2002; Altieri, 2009). Considerable potential exists to improve productivity and efficiency using appropriate technology and innovations (IAAST, 2009). Traditional systems have benefited less from investments in research and development or technical assistance from the state or the private sector. In many cases, indigenous populations have seen their traditional systems collapse due to increasing pressure from population growth and resulting impacts on access to land (IAAST, 2009; Chang, 1977; Grigg, 1974).

Industrial System

This system seeks to intensify production, optimise outputs and reduce costs in order to maximise competitiveness in regional, national and global markets. It is characterised by high inputs of capital and significant reliance on technologies such as pesticides, irrigation, machinery and chemical fertilisers. Industrial farming often involves the cultivation of one single crop, or 'monoculture', over a wide area. These farming systems use the 'Green Revolution' technologies that were developed in the 1980s and 1990s using improved varieties that respond to high levels of fertiliser and where necessary, irrigation. Monocultures are usually single strains that have been bred for high yield and are resistant to certain common diseases. Greater yields can be achieved from cultivating monocultures because planting, maintenance and harvesting methods can be standardised. The application of this technology has been credited with the substantial increases in food production of the past 3 to 4 decades that have fed the world's quickly increasing population. Nonetheless, monocultures maybe more vulnerable to climate change and oversimplified farming systems are likely to be less able to cope with a changing climate (Fraser, 2007; Cotter and Tirado, 2008).

Due to the high investment required, industrial farming is widespread in developed nations. There are considerable limits to the application of these practices amongst small-scale farmers in developing countries, and especially in Africa. Motorised mechanisation has only penetrated parts of the developing world, and even where it is present, high costs mean that it is affordable only to a few actors that have the necessary capital or access to credit (Mazoyer, 2001).

The sustainability of the industrial agricultural production system relies on technologies and methods that have gradually, yet persistently, produced negative environmental impacts such as desertification, deforestation, water resource pollution, and loss of plant and animal biodiversity (UNEP, 2010). The challenge for the future is to sustain high levels of food production with less environmental impacts, but also less dependence on external inputs whose availability is dependent on cheap oil. Some propose that biotechnology can increase the efficiency of high productivity agricultural systems by creating crops that are more productive under more limiting conditions such as reduced nutrient and water availability, or are more resistant to pests and diseases, reducing the need for use of pesticides.

Agroecological System

An agroecological approach to agricultural production provides a range of productive and sustainable practices that create fewer negative environmental and social impacts while seeking to sustain productivity (Ensor, 2009; De Schutter, 2010; IAAST, 2008; FAO, 2008a; Altieri and Nicholls, 2005; SARD, 2007). Agroecology encompasses a range of agricultural systems that employ an understanding of environmental systems to both draw on and replenish natural resources. The focus of the approach is on the entire ecological system to generate environments that are productive and naturally resource conserving, while being socially sustainable: culturally sensitive, socially just and economically viable (Ensor, 2009). agroecology utilises both indigenous farming knowledge and selected modern technologies to manage diversity, incorporate biological principles and resources into farming systems, and intensify agricultural production. It offers a practical way to restore agricultural lands that have been degraded and provides an affordable way for small-holders to intensify production in marginal areas (Altieri et al, 1998). According to a recent report submitted by the Special Rapporteur on the right to food, Olivier De Schutter (2010), agroecology “not only shows strong conceptual connections with the right to food, but has proven results for fast progress in the concretisation of this human right for many vulnerable groups in various countries and environments. Moreover, agroecology delivers advantages that are complementary to better known conventional approaches such as breeding high-yielding varieties. And it strongly contributes to the broader economic development”.

The report also asserts that agroecology is now widely supported as a key strategy for improving the resilience and sustainability of food production systems. Supporters include the scientific community (IAAST, 2008) and international agencies and organisations, such as the United Nations, Food and Agriculture Organisation (FAO, 2008a), UNEP (Altieri and Nicholls, 2005) and Biodiversity International (SARD, 2007). Based on this consensus, this guidebook provides information on a range of technological options that can be implemented to achieve sustainable food production in the context of climate change. The transition of agricultural production systems is a long-term process that will present a range of challenges – agronomically, economically, and educationally. At present, there is no concerted effort or investment in ecological approaches. The practice and success of agro-ecological agriculture on a large scale therefore requires support from research institutions dedicated to agro-ecological methods of fertility and pest management, a strong extension system, committed governments and support from consumers (Badgley et al, 2006).

Agroecological Agriculture and Climate Change

Altieri and Koohafkan’s review (2008) of traditional and small-scale agroecological farming provides examples of common practices and methods that build resilience against climate change, summarised in Box 2.2.

Box 2.2 Agroecological Approaches That Build Resilience

Complex systems: In traditional agroecosystems the prevalence of complex and diversified cropping systems is of key importance to the stability of peasant farming systems, allowing crops to reach acceptable productivity levels in the midst of environmentally stressful conditions. In general, traditional agroecosystems are less vulnerable to catastrophic loss because they grow a wide range of crops and varieties in various spatial and temporal arrangements.

Use of local genetic diversity: In most cases, farmers maintain diversity as insurance against future environmental change or to meet social and economic needs. The existence of genetic diversity has special significance for the maintenance and enhancement of productivity of small farming systems, as diversity also provides security to farmers against diseases, especially pathogens that may be strengthened by climate change. By mixing crop varieties, farmers can delay the onset of diseases by reducing the spread of disease-carrying organisms, and by modifying environmental conditions so that they are less favourable to the spread of certain pathogens.

Soil organic matter enhancement: Throughout the world, small farmers use practices such as crop rotation, composting, green manures and cover crops, agro-forestry. These are all practices that increase biomass production and therefore actively accumulate organic matter. Soil management systems that lead to the maintenance of soil organic matter levels are essential to the sustained productivity of agricultural systems in areas frequently affected by droughts.

Multiple cropping or polyculture systems: Studies suggest that more diverse plant communities are more resistant to disturbance and more resilient to environmental perturbations. Intercropping, which breaks down the monoculture structure, can provide pest control benefits, weed control advantages, reduced wind erosion, and improved water infiltration.

Agro-forestry systems and mulching: Many farmers grow crops in agro-forestry designs and grow shade tree cover to protect crop plants against extremes in microclimate and soil moisture fluctuations. Farmers influence the microclimate by retaining and planting trees, which reduce temperature, wind velocity, evaporation and direct exposure to sunlight and intercept hail and rain. It is internationally recognised that agro-forestry systems contribute simultaneously to buffering farmers against climate variability and changing climates, and to reducing atmospheric loads of greenhouse gases because of their high potential for sequestering carbon.

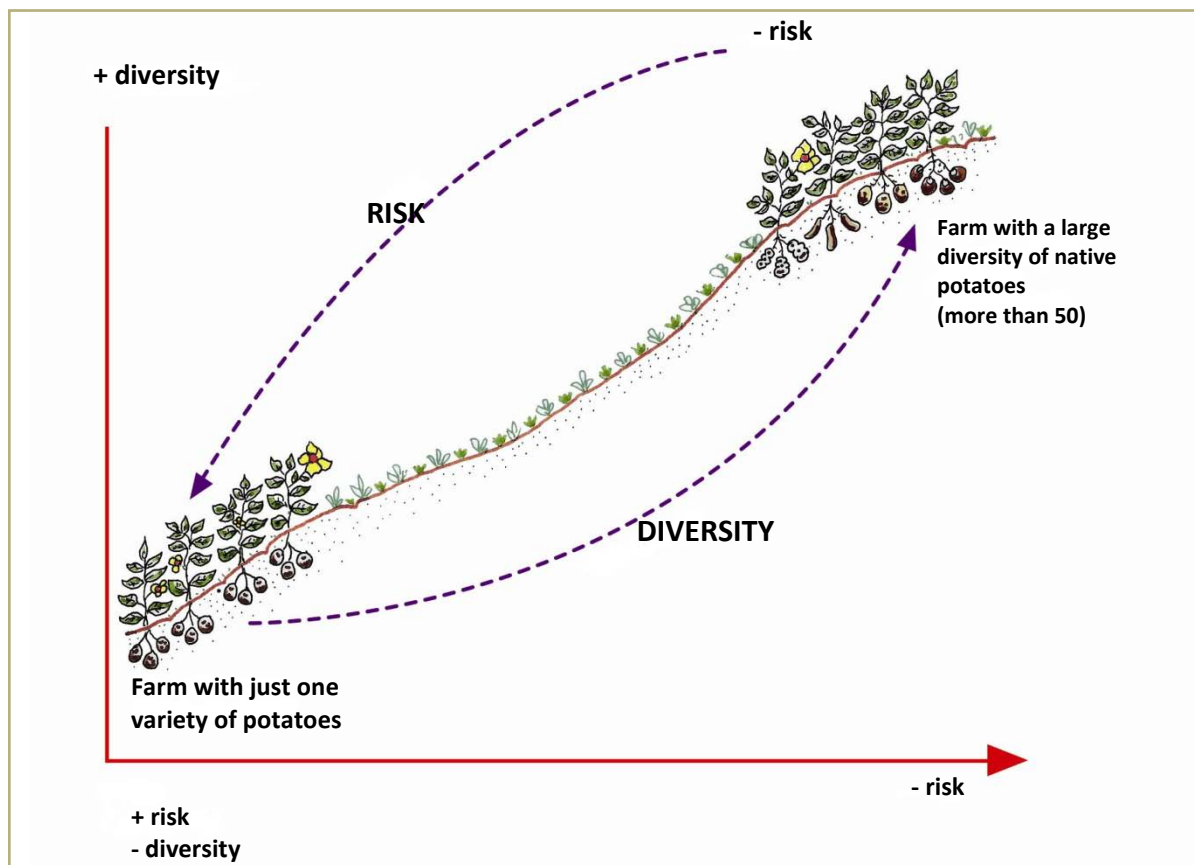
Home gardening: Home gardening is a term to describe the cultivation of small plots used to grow food either adjacent or close to the home or area of habitation. They are fertilised with household wastes and are rich in plant species diversity, usually maintaining 30 to 100 species. This practice provides diversification of crop species and is of economic importance because of its food and nutritional (balanced diet) and medicinal value to the household. The farmer obtains food products, firewood, medicinal plants and spices, and some cash income all year round. These self-sustaining systems are ecologically and economically very efficient.

Source: adapted from Altieri and Koohafkan (2008) and Altieri, M.A. (2002)

The risks that affect crops and animals are primarily related to a total or significant loss of harvests or livestock due to pests, disease and adverse climate events or loss or reduction in biodiversity. Extensive agricultural research has demonstrated that there is an inversely proportional relationship between the

diversity of biota in the agricultural ecosystem and risk. This is to say more diverse systems carry less risk (Altieri and Nicholls, 2009; Ensor, 2009) (Figure 2.4). Biodiversity in all its components (for example, genes, species, and ecosystems) increases resilience to changing environmental conditions and stresses, so genetically-diverse populations and species-rich ecosystems have greater potential to adapt to climate change (FAO, 2007; 9).

Figure 2.4 Relationship between the Agro-biodiversity of Potatoes and Risks



Source: Torres and Gómez, 2008

Diverse ecosystems provide regulatory functions that enable them to adjust to changing conditions. For example, healthy soils contain a high diversity of soil biota. They are more effective at absorbing and retaining moisture than degraded soils, and are thus better able to cope with a drying climate or intense rainfall events. Diverse ecosystems, on the other hand, exhibit resilience in the face of emerging pests or an increase in pest numbers under new climate conditions. Similarly, a livelihood built around species diversity is well positioned to make gradual adjustments in crop or species selection strategy based on observed changes in yields and quality. However, dealing with slowly changing conditions also requires attention to adaptive capacity, through individuals or communities able to make changes to their livelihoods or livelihood strategies in response to emerging climate change. This creative and innovative component of adaptation is essential if farmers are to address the future uncertainty and location specific nature of climate change impacts. It is a central feature of agroecological practice, which depends on the local capacity to manage natural resources (Ensor, 2009).

The technologies presented in this guidebook adhere to the principles of agroecology set out in this chapter. Each of the technologies presents an opportunity for small and large-scale producers to improve productivity levels in order to meet future requirements for food security and global food supply while at the same time fostering sustainable productive environments, building resilience in farming practices and building the adaptive capacity of communities (Ensor, 2009).

2.3 Levels of Adaptation

Climate change adaptation includes initiatives and measures to reduce the vulnerability of human and natural systems facing actual or expected impacts of climate change (IPCC WG II, 2007; 76). Adaptation, then, involves the implementation of a range of strategies including local and introduced biotechnology, hard technologies (machinery, equipment, and tools), soft technologies (knowledge, capacity building, and awareness raising) and organisational technologies (institution building and resource user organisation).

There are various levels at which climate change adaptation technologies can be developed and implemented within the national context:

- Individual/household
- Community/local government
- Intermediate-level institutions
- National government
- International institutions.

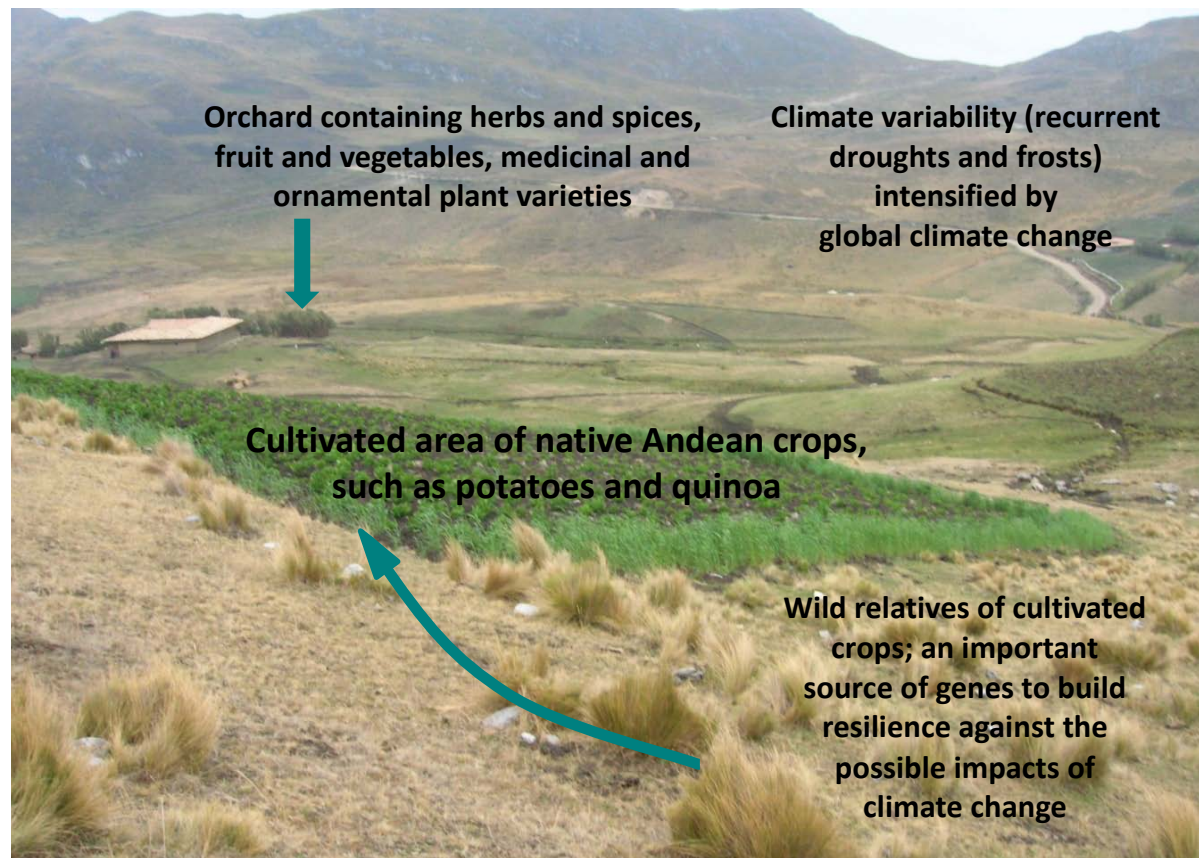
Individual/Household Activities

In the context of agriculture, individual/household level activities relate to technologies adopted by small-scale farmers (or livestock herders and fishers and so on). Over centuries small-scale farmers have independently developed agricultural production systems adapted to local climatic, economic and social conditions (Altieri and Nicholls, 2009). These strategies enable production even in fragile environments, on marginal lands, with unpredictable climate variability and with basic agricultural inputs (such as tools and fertilisers). Many of these strategies are closely linked to the natural physical and biological diversity that characterise ecosystems. In general, traditional, diverse agro-ecosystems are less vulnerable to large-scale losses. Firstly, they exhibit resistance to shocks and stresses through the increased health of the system components and the ability to maintain their function due to the complex interaction of the ecosystem components. Examples include, regulating the impact of diseases, the emergence of pests, the supply of nutrients or the flow of water. Secondly, in the event of an unexpected climatic event, the diversity of crops (including animals and fish) also provides a livelihood safety mechanism. This is because different crops, animals, and fish will respond to climate scenarios in different ways. Whereas the cold may affect one crop negatively, production in another one may increase. Diversity therefore helps reduce the risks created by climate variability aggravated by climate change.

With the support of governments and of several organised households, examples of household-level agricultural adaptation strategies can include:

- Adoption of climate resilient agricultural practices (for example, relying on diverse crops including drought resistant varieties and selective breeding of animal species)
- Adequate storage/shelter for crops/animals
- Sufficient reserves of food supplies.

Figure 2.5 Diversified Cultivation and Conservation of Native Varieties: a Household Climate Change Adaptation Strategy in the High Mountain Ecosystem



Source: photo from Dora Velásquez (2008); text by Juan Torres

Community/Local Government

Community-based adaptation (CBA) starts from a local context and seeks to optimise the capacities, knowledge and practices of coping that are used in the community. CBA aims to enable communities to understand and integrate the concept of climate risk into their livelihood activities in order to cope with and respond to immediate climate variability and long-term climate change. In relation to the agriculture sector, CBA can be supported by a range of actors operating at the local level including resource user groups, farmer's unions and associations (such as for seed distribution, animal health) and local government (such as departments for agriculture and for the environment). The participation of these local institutions is vital, given that local institutions know their communities and should have the main responsibility for identifying the poor and vulnerable and supporting them in building safe rural and urban settlements. These institutions should ensure that dissemination of climate information reaches the poorest and most vulnerable through appropriate extension services (Commission on Climate Change and Development, 2009).

In contrast to the more autonomous implementation of adaptation strategies at the individual/household level, community and local government initiatives need more comprehensive, coherent and systematic approaches. The impacts of climate change vary from place to place, so the adaptation needs are location specific. Effectively CBA consists of a decentralised approach that promotes collaboration and coordination between different actors. CBA encourages local communities to identify and prioritise their

adaptation needs and to seek funding from the local authority. The nature and responsiveness of local decision-making processes will depend largely on an effective network of public and private stakeholders that includes community participation and is supported by a supportive policy environment.

Intermediate-Level Institutions

Intermediate-level refers to institutions between local and national, for example, region or district level government. These institutions are often responsible for operating over an area that can be particularly relevant for agricultural adaptation strategies because they focus on a territory whose management is consistent with agricultural production units, such as a watershed. Environment and agriculture ministry institutions, research institutes and NGOs are particularly relevant for the agriculture sector.

Capacity problems in these intermediate-level institutions, particularly in remote rural areas, can be a principal barrier to effective community-based action. There is in many cases a need to realign institutions to work for the poor. The need to build the capacity of those with responsibility in these institutions to work with NGOs and community-based organisations (CBOs) must go hand in hand with mobilising CBOs to make claims from and engage with these institutions. There is also a need to address national policies that restrict regional or district authorities' freedom to act. Work may, then, be necessary at the local, meso and national levels simultaneously (Ensor, forthcoming 2011).

National Level

Climate change concerns need to be mainstreamed into national policies, prioritising the needs of the most vulnerable people and sectors. For communities to benefit from national interventions, local and national capacity needs to be built. At the national level, governments are strongly focused on a sectoral, top-down approach that involves integrating adaptation priorities and actions into existing or future sustainable development plans (UNFCCC, 2009). The principal mechanism guiding national level adaptation planning in the Least Developed Countries (LDCs) and some developing countries is the National Adaptation Programme of Action (NAPA) which is based on available information and contains a list of prioritised adaptation actions and projects (see Chapter 3.3 for further details and Box 2.3 for the NAPA process).

Box 2.3 The NAPA Process

The steps for the preparation of the NAPAs include the synthesis of available information; participatory assessment of vulnerability to current climate variability and extreme events and of areas where risks would increase due to climate change; the identification of key adaptation measures as well as criteria for prioritising activities; and the selection of a prioritised list of activities. The development of a NAPA also includes short profiles of projects and/or activities intended to address urgent and immediate adaptation needs.

Source: UNFCCC, 2002

In many developing countries, agriculture, land and livestock will be positioned as key sectors in which measures must be taken to reduce vulnerability to climate change. These plans will provide orientation to the national agriculture research and development organisations in their priority areas for future action. Generally such plans prioritise the basic food crops that sustain the food security of the population locally and nationally. Increasingly national agricultural research services are working on improving estimates of the potential impact of climate change and with extension services looking to improve access to crop varieties that are more drought or heat tolerant. However, actions also include social development agencies and

disaster preparedness to ensure the national capacity to respond to food scarcity or a natural disaster; and also financial preparedness to ensure sufficient financial reserves to respond to a disaster and developing financial mechanisms such as climate insurance to buffer impacts. Private companies can also play a role in promoting adaptation, as they are also concerned about the effects of climate change on the production, on which their businesses depend. In some cases they can invest in testing adaptation technologies or financing the application of them by producers.

However, frequently, the poor and marginalised face challenges that demand locally relevant technologies rather than interventions which are suitable for broad application (Ensor, 2009). Ensuring that the needs of remote, vulnerable and marginalised communities are fully integrated in national adaptation strategies is a significant new challenge for governments. Multi-stakeholder platforms or climate change learning alliances, such as those being piloted in Tanzania and Malawi, can provide a means to integrate the needs of local communities with national research, extension and development agencies. Processes that enable the participation of civil society in identifying priorities and developing adaptation plans will be required for this to be successful (see Chapter 3).

International Research and Development Institutions

Local empowerment and participatory processes are essential. These can be complemented by the efforts of international agencies including the 15 research centres which form part of the Consultative Group for International Agricultural Research (CGIAR) who can support the agriculture sector to adapt to climate change. They can:

- Support risk management through enhanced prediction of climate impacts on agriculture, and associated climate information and services. The use of GIS approaches linked to modelling of crop growth can provide more detailed analyses under different scenarios of climatic impacts on different crops, including the probabilities of extreme weather events. As farmers and their organisations make use of this information it can help them to engage in adaptive behaviour to mitigate the effects of climate change and reduce risks.
- Contribute to developing varieties and other new technology with drought and heat tolerance. Both local varieties and others have traits for drought and heat tolerance. Conventional breeding (non-Genetically Modified Organisms) with careful selection of parental materials and making use of local genetic diversity can be used to accumulate these traits and develop varieties better adapted to climate change. In addition, climate change is expected to lead to an increase in pests and diseases. Conventional breeding can be used to increase resistance to these and complement farmers' own management practices.
- Support innovation processes and encourage spill over of technology developed in one country to other countries in the region. CGIAR centres hold in trust germplasm and improved varieties and can help promote the exchange of clean planting material from one country to another. The CGIAR centres because they function internationally across several continents can also help in promote the use of other types of technology which was generated in one country in other countries where it is also relevant.

Other international organisations, both public ones such as the World Bank or regional development banks, and international development NGOs play an important role in generating and sharing knowledge and piloting adaptation processes to the challenges of climate change. Even multi-national companies are concerned about the impacts of climate change and in some cases are investing in the development of technologies that they hope may contribute to stabilising the supply of commodities to their industry.

3. Adaptation Decision-making and Prioritisation of Technologies

Since climate change is an unfolding challenge with no known end point, adaptation needs to be understood and operated as a process, through which communities gain access to skills, resources and information so that they can continuously shape their lives and livelihoods as the environment changes around them (Ensor, 2009). The ongoing nature of climate change and the inherent uncertainty in weather and climate projections necessitate an approach to decision-making that empowers communities. The approach should build their capacities and offer them opportunities to play an informed role in decision-making – over the technologies and strategies that are most appropriate to their needs, over which resources are needed, and the proper timing. Known as ‘adaptive capacity’, this ability to adjust to a changing environment is built by supporting communities to play a leading role in defining their own responses to climate change, through, for example, active participation in planning, resource prioritisation and knowledge sharing (Ensor and Berger, 2009c; Chapin et al, 2006; Smit and Wandel, 2006).

The process of decision-making around adaptation strategies should consist of several fundamental components:

- Participatory vulnerability and risk assessment
- Identifying and prioritising options for adaptation
- Participatory technology development and implementation
- Reviewing the effectiveness of the adaptation measures and actions.

Decision-making at each of these stages should be an empowering process that builds relationships and opens new spaces for consensus building, contributing to local adaptive capacity. A crucial element to this process is that it should involve the participation of the full range of local, regional and national actors (depending on the level of intervention, see Chapter 2.3), including communities, social organisations (such as farmer unions and resource user groups), non-governmental institutions (such as CBOs, NGOs, research institutes, and international agencies), and the private sector and government agencies. Participatory processes are essential for developing adaptation policies and for adaptation technology selection, development, implementation and monitoring so that the communities themselves are represented in decision-making that is able to capture the dynamics of local livelihoods (Soluciones Prácticas, 2011; Patt, 2008).

3.1 Vulnerability and Risk Assessment

Vulnerability to climate change is the degree to which communities are susceptible to, and unable to cope with, adverse impacts (IPCC WG II, 2007; 48). Community-based vulnerability and risk assessments are widely used by development and humanitarian organisations to design climate change adaptation programmes (Red Cross/Red Crescent Climate Centre 2005; 8). In this way, communities are involved from the very first stages of adaptation strategy planning.

There are many methods of community risk assessment (CRA) used by NGOs and other organisations to assess local and community vulnerability and capacity (Van Aalst et al, 2007; 166); many of them can be found on the ProVention website (see Box 3.1 below). After analysing several case studies, Van Aalst et al concluded that the CRA methodology provides a valuable tool for climate change adaptation. It is especially useful to inform bottom-up approaches to climate change adaptation that are receiving increasing attention within the UNFCCC and among development specialists (Van Aalst et al, 2007; 177).

Box 3.1 Resources for Vulnerability and Risk Assessment

Methodologies of Disaster Risk Assessment

- Community risk assessment (CRA) – ProVention (2011)
- Vulnerability and capacity assessment (VCA) – IFRC (2007)
- Climate Vulnerability and Capacity Analysis (CVCA) – CARE (2009)
- V2R Framework – Practical Action (2009)
- Participatory Capacities and Vulnerabilities Assessment (PCVA) – Oxfam (De Dios 2002)
- Participatory Vulnerability Analysis (PVA) ActionAid (<http://www.actionaid.org.uk>)

Main Sources

- ProVention – http://www.proventionconsortium.org/CRA_toolkit.htm
- Red Cross / Red Crescent Climate Centre <http://www.climatecentre.org/>
- Eldis Community-based Adaption Exchange – <http://www.eldis.org/index.cfm?objectid=63551B3B-FDA9-0941-1EAC7111660B5FC5>
- UN International Strategy for Disaster Reduction <http://www.unisdr.org/>
- Practical Action <http://practicalaction.org/practicalanswers/index.php?cPath=87>
- Prevention web – <http://www.preventionweb.net/english/>

Participatory vulnerability and risk assessments often require facilitation (Van Aalst et al, 2007; 169). The implementation of some tools requires the imparting of knowledge to the community from ‘above’ – or at least from outside. This is because unlike other key issues in development there is very little grassroots awareness of climate change issues and a lack of knowledge of the additional risks related for local livelihoods (Van Aalst et al, 2007; 170). Stronger linkages are needed between organisations facilitating these processes and suppliers of climate information, particularly in terms of ensuring availability of climate information at the community level (Van Aalst et al, 2007; 165).

3.2 Identifying Options for Adaptation

Availability of information from climate monitoring systems, and in many areas with no weather stations, gathering information from local population knowledge, is very important for the process of selecting technologies for climate change adaptation. However, a climate scenario approach to identifying adaptation options can be problematic. Different models produce a wide range of different scenarios which may not represent the full range of future possibilities. Implementing adaptation options that rely heavily on climate predictions could lead to maladaptation if climate changes turn out differently from what is forecasted.

Diversity is central in the decision-making process of selecting adaptive agricultural technologies, to create better conditions for increasing resilience in agricultural systems to cope with uncertain scenarios

of the next decades. According to Ensor (2009), diversity helps create conditions for increased resilience because at all levels (physical, natural, economic and social) diversity improves the viability of a balanced socio-ecological system. For example, an agricultural production system that relies on a single crop has low resilience to climate change or disease compared with one based on agricultural biodiversity.

Based on this understanding, two strategies are proposed for the selection of adaptation options:

- When addressing current, existing vulnerabilities to climate change impact-specific measures can be implemented to build adaptive capacity. For example, if a region is currently experiencing droughts every year, then adaptation options can be selected to tackle this scenario directly, such as developing resilient crop species.
- When looking at future climate impacts, uncertainty about climate scenarios means that increasing the diversity of productive activities and biological cycles is an appropriate strategy as this will help to build adaptive capacity. Implementing so-called 'no-regret' measures supports the generation of net social benefits under all future climate change scenarios, focusing on reducing vulnerability while strengthening the capacity to adapt through sustainable development. Options could include selecting resilient crop varieties, increasing the variety of cultivated species, domesticating new species, implementing agro-forestry, and establishing farmers' organisations among others.

Creating Conditions for Successful Adaptation

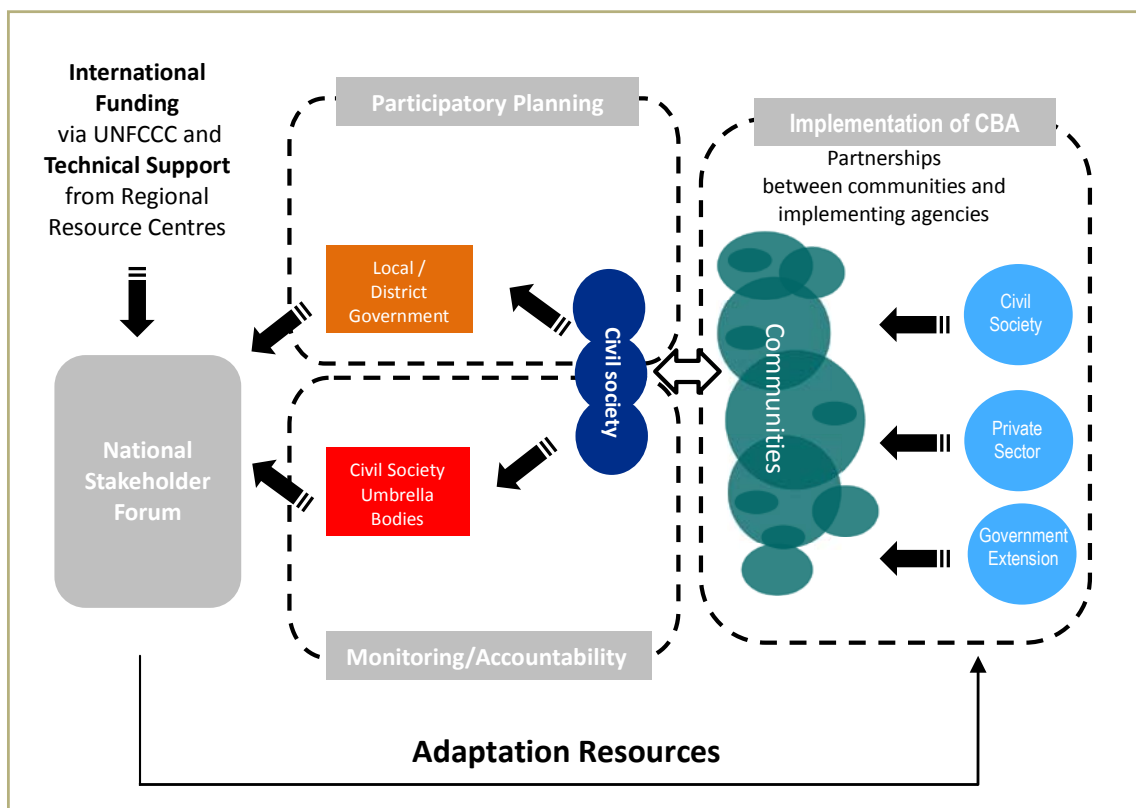
In numerous countries civil society groups, research institutes and donors have formed National Climate Change Working Groups and National Stakeholder Forums. These groups advocate for the incorporation of climate change adaptation into government policies and programmes by undertaking relevant thematic research fact finding and participating in national policy and bill drafting processes.

However, even where national level actions are focused on sectors that are particularly important to the poor, such as agriculture and water, they often fail to meet the needs of the country's most vulnerable people. This is due to a variety of factors, including insufficient participation of civil society to identify priorities; the necessity for locally appropriate technologies rather than broad sector-wide interventions; and inability of the state infrastructure to provide services to rural areas (Ensor and Berger, 2009c). As a bottom-up approach, Community-based Adaptation (CBA) can provide a framework for inclusive governance that engages a range of stakeholders directly with local or district government and national coordinating bodies, and facilitates participatory planning, monitoring and implementation of adaptation activities (see Figure 3.1).

In this proposal, the considerations for each group of stakeholders are:

- **National Stakeholder Forum.** This body links international, national and local decision-making by receiving funding and regional or international technical support, while coordinating adaptation planning and distributing resources. Ideally, it should be an integral part of national development planning to avoid adaptation being treated in isolation, reflecting the impact of climate change across all sections and sectors of society and the interrelationships between adaptation and mitigation. Its composition should include a mix of representatives, including those from government, civil society, the private sector, academia and the media. It has responsibility for formulating and reviewing national adaptation plans on an ongoing basis, informed by civil society members who provide inputs based on the perspectives of their constituencies. The inclusion of civil society members, such as vulnerable, minority or faith groups, or low income producer representatives, also brings accountability by providing a mechanism through which diverse voices can be heard.

Figure 3.1 How Community-based Adaptation (CBA) Could Be Implemented, Engaging Civil Society in Planning, Monitoring and Implementation



Source: Ensor and Berger, 2009c.

- **Participatory planning** facilitates bottom-up planning, funnelling community plans and priorities up to the national forum via the local or district government. It is equally possible for community-based organisations (CBOs) to undertake participatory planning themselves, or with the support of NGOs, or to act as a link between government representatives and the communities. While the role for CBOs will vary with context, they are vital as either partners in or providers of participatory processes. Both CBOs and governments are likely to need capacity support to be able to provide and utilise participatory planning.
- **Implementation of community-based adaptation** takes place through partnerships between the implementing agency (an NGO or civil society organisation, the private sector, or government extension service) and the community, thereby building community members' capacities through exposure to outside expertise while incorporating local knowledge into adaptation actions. Funding for implementation could be direct to the implementing agency from the national forum or via regional government to implement community plans. Implementation activities will need to include a combination of actions to reduce vulnerability to hazards, increase resilience and build the adaptive capacity of communities.
- **Monitoring and accountability** is critical to ensure funding is reaching communities and supporting appropriate activities. Representatives of civil society umbrella bodies holding seats on the national stakeholder forum provides a mechanism for accountability, through which the results of monitoring of adaptation planning and implementation at the community level can reach the decision-making forum.

The second power sharing strategy is the use of deliberative inclusive processes (DIPs) to influence the direction of science and research policy. The use of citizens' juries, consensus conferences or future search exercises is needed to ensure the different interests and priorities of marginalised communities are represented in the research and funding choices made in the natural and social sciences. DIPs can be used by those supporting adaptive capacity as a mechanism to promote power sharing in research, and thus experimentation and testing that is undertaken by or relevant to the interests of the poor, by focusing on three key areas (adapted from Pimbert, 2006; 16):

- Reorganise conventional scientific and technological research to encourage participatory knowledge creation and technological developments that combine the strengths of poor communities and scientists in the search for locally adapted solutions. Effective and interdisciplinary partnerships are needed to link natural and social sciences with indigenous knowledge to address needs and problems in specific local settings that are typically marked by complex and dynamic change. An important goal here is to ensure that knowledge, policies and technologies are tailored to the diversity of human needs and the situations in which they are to be used. This must be on the basis of an inclusive process in which the means and ends of research and development are primarily shaped by and for citizens through conscious deliberation and negotiation.
- Open up decision-making bodies and governance structures of research and development organisations to allow a wider representation of different actors and greater transparency, equity and accountability in budget allocation and decisions on of research and development priorities. They are immensely powerful in that they broadly decide which policies and technologies will ultimately be developed, why, how and for whom. And yet the policies and decisions concerning science and technology of research and development are often made by people who are increasingly distant from rural realities and moving closer to corporations.
- Ensure that knowledge and innovations remain accessible to all as a basic condition for economic democracy and the exercise of human rights, including the right to participation. Decisions to issue patents on knowledge embodied in products and processes (such as seeds and software) and national intellectual property rights legislation require more comprehensive public framing of laws and policies based on deliberative and inclusive models of direct democracy (Ensor, forthcoming 2011).

3.3 Key Criteria for Prioritisation of Adaptation Technologies

When it comes to prioritising technologies for climate change adaptation, the following criteria should be discussed and evaluated by the range of actors within the CBA framework.

- **Environmental.** The extent to which the technology conserves and strengthens biological diversity and promotes environmental sustainability. This is an important criterion because biological diversity increases resilience of the ecosystem and therefore of the community (where technologies are selected to work in harmony with natural biodiversity). The technology should also promote sustainable local resource use, for example, the hardware technology can be manufactured and serviced locally where possible.
- **Awareness and Information.** The extent to which the technology enables and facilitates (i) access to information about climate change and the uncertainty of future conditions, (ii) integration of information from seasonal and weather forecasting and early warning systems into decision-making processes, and (iii) strengthening information systems in general (and with local knowledge more specifically).
- **Productivity.** The extent to which the technology (i) supports natural life cycles (nutrients of soil and water) and thus, conserves adequate biological conditions for future production; (ii) enables farmers

to produce enough for self-consumption (to achieve food security), (iii) improves crop quality and productivity; (iv) improves crops quality and (v) is of easy dissemination and replication.

- **Economic.** The extent to which the technology: (i) Strengthens existing productive systems. For example, growing maize starch in rural household plots provides a product for human consumption and food for cattle. Livestock activities can generate manure for organic fertiliser. (ii) Increases the amount of information about variations of prices of inputs and final products in the different months of the year. This protects and enables farmers to produce a surplus that can be sold on local markets to generate additional income. (iii) Reduces transaction costs of productive and commercial activities, for example, transportation costs, credit and rural insurance costs, costs incurred due to theft, among others. (iv) Does not generate influence, power and natural resource management inequities, which could be the source of social conflicts that obstruct the development of productive activities.
- **Cultural.** The extent to which the technology (i) respects cultural diversity, (ii) allows for an intercultural dialogue and the incorporation of ancient and local knowledge, and (iii) is understandable and easily applied by farmers in their current context.
- **Political.** The extent to which the technology is integrated coherently into regional and national policies and can be scaled-up for wider implementation.
- **Institutional.** Strong institutions can sustain development and are vital for implementing adaptation measures. Adaptation technologies should therefore be evaluated and prioritised based on the extent to which they strengthen formal and informal institutions, such as government ministries, civil society organisations and community-based organisations by building capacity for planning and execution of adaptation strategies. Technologies should also support civil society to form social networks and participate in decision-making processes.

The Fundamental Role of Culture

Culture plays an important role in the process of adaptation. Culture can be understood as “the sum total of the material and spiritual activities and products of a given social group a coherent and self-contained system of values and symbols as well as a set of practices that a specific group reproduces over time and provides individuals with the signposts and meanings for behaviour” (Stavenhagen, 1998;. 5). Culture can provide, alter or limit options for adaptation and can determine how individuals within communities respond to the prospect of changes to their lives and livelihoods in the face of climate change. While some cultures exhibit a readiness to embrace change, others lack a tradition or history of adaptation and require an approach that builds from the existing cultural context and is sympathetic to local notions of well-being. However, in all cases an explicit reference to the role of culture is necessary to ensure that this inherent strength of community-based adaptation is delivered in practice (Ensor, 2009).

Box 3.2 Incorporating Local Culture into Adaptation Strategies: Fish Harvesting and Floating Gardens in Bangladesh

Bangladesh is the floodplain for several large rivers flowing from the Himalayas. The rivers change their course annually during the monsoon season when vast areas of the country are routinely submerged. Whilst the flow of these rivers is projected to increase as glaciers melt under the influence of climate change, even at present it is not unusual for large areas of land to disappear on one side of the river, while new sandbanks emerge on the other. Erosion results in community members losing most of their assets (and of course their land) several times in a decade, forcing them to relocate.



Women and boy tending the crops on floating gardens Gaibandha District, Bangladesh

Source: Practical Action



Locally managed fingerling production system via cage aquaculture in Bangladesh

Source: Practical Action

Practical Action has worked with these communities to identify key vulnerabilities and develop technologies that build on practices already in use in similarly affected communities so that resilience is increased and livelihoods strengthened. For example, fish is a key ingredient in the local diet, but during the monsoon season, the river's flow is too strong for local fishing boats. Flood water creates additional temporary water bodies, giving the opportunity for fish cultivation. By training people to construct cages from bamboo and netting, families are enabled to breed fish for food and income generation. As floods worsen and longer period of inundation are experienced, the planting of crops is delayed. By developing floating vegetable gardens – a practice prevalent in coastal regions – using locally available materials, seedlings can be reared ready for planting as soon as flood waters recede. Practical Action's experience of working with these communities has been that they have embraced adaptability as a part of their cultural response to their harsh environment. The people have shown themselves to be open to developing new practices and livelihood options that strengthen their coping strategies. Note, however, that whilst this suggests a context that is receptive to changes in livelihood strategies, strong cultural forms still need to be recognised. Reflections on Practical Action's experiences in Bangladesh highlight how pre-existing formal and informal institutions and patterns of behaviour should be acknowledged and also incorporated into policy or project design and approach, rather than bypassed or challenged. Adaptation interventions must acknowledge that even in the most flexible societies, the mechanisms of change will inevitably be framed by a cultural context that may be the entry point for interventions.

Source: Ensor and Berger, 2009b

4. Concrete Adaptation Technologies and Practices in the Agriculture Sector

In this chapter, 22 adaptation technologies are showcased that have been implemented in the agriculture sector in developing countries. For each technology, the following elements are considered:

- A description of the technology, how it is implemented and how it contributes to climate change adaptation
- The technical advantages and disadvantages
- Knowledge and monitoring requirements
- Costs and financial requirements
- Institutional and organisational requirements
- Barriers to and opportunities for implementation
- Real case of application.

The technologies cover monitoring and forecasting the climate, sustainable water use and management, soil management, sustainable crop management, seed conservation, sustainable forest management and sustainable livestock management. The technologies include a range of hardware, software and orgware components, and often a combination of all three. Table 4.1 shows the portfolio of technologies presented.

Table 4.1 Adaptation Technologies

	Technology	Scale	Case Study
Planning for Climate Change and Variability	National climate change monitoring system	Large	Zimbabwe, Kenya and Brazil
	Seasonal to inter-annual prediction	Large and small	Eastern Europe and Lesotho, Burkina Faso
	Decentralised community-run early warning systems	Small	West Africa and Peru
	Climate insurance	Large or collective	Peru, Vietnam, Mongolia, Mexico
Sustainable Water Use and Management	Sprinkler irrigation and dripping irrigation	Large and small	Indonesia, Zimbabwe and Peru
	Fog harvesting	Small	Nepal
	Rainwater harvesting	Large and small	Paraguay, Philippines and India
Soil Management	Slow-forming terraces	Large and small	Ecuador, Philippines
	Conservation tillage	Large and small	Brazil, Philippines
	Integrated nutrient management	Large and small	Uganda and India, Nicaragua

Contd...

Sustainable Crop Management	Crop diversification and new varieties	Large and small	Uganda, India
	New varieties from Biotechnology	Large and small	India, Africa
	Ecological pest management	Large and small	Indonesia, Africa and India
	Seed and grain storage	Large and small	Afghanistan and Kenya
Sustainable Livestock Management	Livestock disease management	Large and small	Peru and Madagascar
	Selective breeding via controlled mating	Large and small	Peru
Sustainable Farming Systems	Mixed farming	Large and small	Bangladesh and Laos, Honduras
	Agro-forestry	Large and small	India, Mexico
Capacity Building and Stakeholder Organisation	Farmer Field Schools	Small	West Africa, East Africa
	Community-based agricultural extension	Small	Kenya
	Forest User Groups	Large and small	Gambia
	Water User Association	Small	Tanzania

4.1 Planning for Climate Change and Variability

4.1.1 Climate Change Monitoring System

It is critical to provide access to information about expected climate changes which should clearly explain the uncertainty involved in estimating future impacts. Monitoring climate change, forecasting impacts and using early warning systems to disseminate data to a range of stakeholders from the national to the local level are all vital components to successful long-term adaptation planning and implementation. Information about climate change should also be spread in ways that will reach everyone affected in a format they can understand. Expanding networks of skilled professionals who can undertake local, regional and national research into climate change and its likely future impacts on agriculture is essential.

Definition

A climate change monitoring system integrates satellite observations, ground-based data and forecast models to monitor and forecast changes in the weather and climate. A historical record of spot measurements is built up over time which provides the data to enable statistical analysis and the identification of mean values, trends and variations. The better the information available, the more climate can be understood and the more accurately future conditions can be assessed, at the local, regional, national and global level. This has become particularly important in the context of climate change, as climate variability increases and historical patterns shift.

Description

Systematic observation of the climate system is usually carried out by national meteorological centres and other specialised bodies. They take measurements and make observations at standard preset times and places, monitoring atmosphere, ocean and terrestrial systems. Since national monitoring systems all form part of a global network, it is vital that there is as much consistency as possible in the way

measurements and observations are made. This includes accuracy, the variables measured and the units they are measured in. The World Meteorological Organisation (WMO) performs a vital role in this respect. The National Meteorological or Hydrometeorological Services (NMHS) of 189 member states and territories form the membership of the WMO. This enables the WMO to establish and promote best practice in national climate monitoring, provide support to the NMHSs and effectively implement specific initiatives.

In 1992 the Global Climate Observing System (GCOS) was established to ensure that the observations and information needed to address climate-related issues are obtained and made available to all potential users. The initiative was co-sponsored by the WMO, the Intergovernmental Oceanographic Commission (IOC) of UNSECO, the United Nations Environment Programme (UNEP) and the International Council for Science (ICSU). The stated goal of GCOS is: “to provide comprehensive information on the total climate system, involving a multidisciplinary range of physical, chemical and biological properties, and atmospheric, oceanic, hydrological, cryospheric and terrestrial processes. GCOS is intended to meet the full range of national and international requirements for climate and climate-related observations. As a system of climate-relevant observing systems, it constitutes, in aggregate, the climate observing component of the Global Earth Observation System of Systems (GEOSS).”³

As part of its role to provide vital and continuous support to the United Nations Framework Convention on Climate Change (UNFCCC), GCOS has established 20 Climate Monitoring Principles⁴, as well as defining 50 Essential Climate Variables (ECVs). Table 4.2 below shows the different types of ECV:

Table 4.2 Essential Climate Variables

Domain	GCOS Essential Climate Variables	
Atmospheric (over land, sea and ice)	Surface: ^[A]	Air temperature, wind speed and direction, water vapour, pressure, precipitation (rain/snow), surface radiation budget.
	Upper-air: ^[B]	Temperature, wind speed and direction, water vapour, cloud properties, earth radiation budget (including solar irradiance).
	Composition:	Carbon dioxide, methane, and other long-lived greenhouse gases ^[C] , ozone and aerosols, supported by their precursors. ^[D]
Oceanic	Surface: ^[E]	Sea-surface temperature, sea-surface salinity, sea level, sea state, sea ice, surface current, ocean colour, Carbon, dioxide partial pressure, ocean acidity, Phytoplankton.
	Sub-surface:	Temperature, salinity, current, nutrients, carbon dioxide partial pressure, ocean acidity, oxygen, tracers.
Terrestrial		River discharge, water use, groundwater, lakes, snow cover, glaciers and ice caps, ice sheets, permafrost, albedo, land cover (including vegetation type), fraction of absorbed photosynthetically active radiation (FAPAR), leaf area index (LAI), above-ground biomass, soil carbon, fire disturbance, soil moisture.

^[A] Including measurements at standardised, but globally varying heights in close proximity to the surface.

^[B] Up to the stratopause.

^[C] Including nitrous oxide (N₂O), chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs), sulphur hexafluoride (SF₆), and perfluorocarbons (PFCs).

^[D] In particular nitrogen dioxide (NO₂), sulphur dioxide (SO₂), formaldehyde (HCHO) and carbon monoxide (CO).

^[E] Including measurements within the surface mixed layer, usually within the upper 15m.

Surface atmospheric conditions are the most straightforward of the ECVs to measure. Accurate measurements can be taken using relatively simple equipment. The following instruments are used to measure the different atmospheric surface variables over land, sea and ice:

- A thermometer for measuring air and sea surface temperature
- A barometer for measuring barometric pressure/air pressure
- A hygrometer for measuring humidity
- An anemometer for measuring wind speed
- A wind vane for measuring wind direction
- A rain gauge for measuring precipitation
- A pyranometer for measuring solar radiation.

These instruments are usually placed together at a weather station at specific locations on the Earth's surface. At sea, dedicated weather buoys are equipped with additional instruments to measure the oceanic ECVs.

The global network provided by the WMO enables the national climate monitoring systems of all the member states to feed data into a central database that is accessible to all. This is a vital resource, particularly for developing countries that would not otherwise have access to data collected using state of the art climate monitoring technology. However, the network also creates a responsibility for all member states to ensure that the data they contribute is of sufficient quality. In general there is a need to improve observations at all levels to enhance countries' ability to adapt to climate change. Effective adaptation planning requires improved observations; improved local, regional, national and global data, as well as denser networks; the recovery of historical data; building of support among the user communities that have a demand for climate information; and promoting greater collaboration between the providers and users of climate information. Working with local populations to incorporate traditional forecasting methodologies can provide key insights into local climate conditions and vulnerabilities that will be essential for effective adaptation planning (Box 4.1).

Box 4.1 Traditional Forecasting with Bio-indicators

Although a traditional practice, forecasting with ancestral bio-indicators can be considered an adaptation technology because studies show that they are complementary to climate predictions issued by national meteorological services (Alvarez and Vilca, 2008). In many cases, bio-indicators are more effective for local-level response and adaptation strategies as they provide a more immediate diagnosis than meteorological warnings issued by centralised state entities and are also more adapted to predicting conditions at the local level (Alvarez and Vilca, 2008).

Developed over years of observation and experience, bio-indicators form an essential part of community strategies for disaster risk reduction and climate change adaptation. In terms of development benefits, ancestral bio-indicators enable farmers to maintain productive farming practices and even to take advantage of changes in climate where this leads to longer periods of suitable weather for crop cultivation, or where they are able to adjust crop type to benefit from new climate conditions. Traditional forecasting methodologies incorporate local observations of climatic and other environmental changes or bio-indicators into social organisation to provide an early warning mechanism for hydro-meteorological phenomena that appear suddenly or over time. Environmental bio-indicators of climate change include changes in the behaviour of animals (for example migration and mating seasons), of plants (such as changes in hydrological tolerance, flowering periods and changes in ecosystem composition) and of weather conditions (such as longer, drier periods, increased frequency of cold periods).

Biological indicators are the subject of scientific research, with studies being conducted into organisms including fish, insects, algae, plants and birds and their role as a form of early detection of El Niño Southern Oscillation (ENSO) events (Guralnick, 2002). Rural farmers have learned to observe local bio-indicators as a basis for making strategic decisions about their agricultural production. One such strategy is the observation of certain bio-indicators several months before sowing and during the crop growth cycle in order to make weather forecasts and predictions and adjust planting and cultivation activities accordingly.

According to Hambly and Onweng Angura (1996), in the Kwale District in Kenya, the end of seasons can be predicted by migration of a specific type of monkey, movement of butterflies and budding of some trees. All of these alert the community to prepare the land. The start of the rains is predicted by the change in winds flowing towards the North, the changes in the position of stars and information given by fishermen on the 'mixing' (inversion of sea water).

In Zimbabwe, interviews with community members captured information on how certain types of trees, birds and some patterns of animal behaviour have, for many years, been used by the Shona people as measures or signals of changes in the quality of their environment. These include: trees as soil fertility indicators, birds as heralds of the rainy season, trees as water level indicators, and abundance of wild fruits as indicators of good rainy season. This approach promotes the active participation of community meteorological observers who keep daily records of local bio-indicators and climate variables captured by basic weather stations installed on their farms. They screen the information, hand over the data to system operators for processing and validation, produce and disseminate weather forecasts and provide guidance and advice (such as on the type of crops or the farming schedule) to their communities in the native language. This model promotes decentralised participatory data collection and monitoring processes which can empower communities to make collective decisions about their livelihood strategies.

The estimated cost of the implementation of a decentralised climate monitoring system that incorporates traditional knowledge in a micro watershed covering 10 local governments is US\$ 50,000. Annual operating costs are estimated at US\$ 25,000 (Damman, 2008). The limitations of the technology are related to potential scale of application which can usually only occur at a very local level. In addition, in some contexts, increased climate variability can throw into question the validity of biological indicators.

Source: Alvarez and Vilca, 2008; Guralnick, 2002; Hambly and Onweng, 1996; Damman, 2008

The Technology and Its Contribution to Adaptation

For countries to understand their local climate better and thus be able to develop scenarios for climate change, they must have adequate operational systematic observing networks, and access to the data available from other global and regional networks. These systems enable the integration of national early warning systems, GIS mapping of vulnerable areas, meteorological information on flooding and droughts, as well as the mapping of disease outbreaks. In this way, they provide indicators for monitoring the impacts of climate change and facilitate disaster preparedness and adaptation planning.

The Food and Agriculture Organisation of the United Nations (FAO) is running a number of initiatives aimed at modelling the impacts of climate change on agriculture which provide vital information for national decision-making and planning (Box 4.2).

Box 4.2 FAO Climate Change and Agriculture Modelling

Climpag (Climate Impact on Agriculture) is aimed at bringing together information on interactions between weather, climate and agriculture in the general context of food security. The programme has developed practical methodologies and tools to help increase understanding of and aid analysis of the effect of the variability of weather and climate on agriculture. One of these tools is agrometeorological crop forecasting that is used to estimate crop yields (t/ha) and production usually a couple of months before the harvest takes place. The FAO approach uses computer models that attempt to simulate plant-weather-soil interactions. Key factors that affect crop yields are fed into the model, which then produces outputs such as maps of crop conditions and yields. Weather data is among the most important data that condition the inter-annual variability of crop yields and are thus an essential crop forecasting input. Other inputs include the 'crop calendar'⁵, crop reports, satellite-based variables such as Normalised Difference Vegetation Index (NDVI) and Cold Cloud Duration (CCD), as well as other factors such as technology, management, prices and government policies and reference data.

FAO-MOSAICC (Modelling System for Agricultural Impacts of Climate Change) integrates four models related to (statistical) downscaling global circulation model data, hydrology, crop growth and assessing impacts of crop yields on national economies. The objective of the system is to assess the impacts of changing crop yields on national economies in order to develop effective adaptation strategies. The system will be rolled out in national institutions in two pilot African countries in 2011 and will be accompanied by significant capacity building and training.

Source: the FAO website www.fao.org/nr/climpag; Kuika et al, 2011

Advantages

There are many advantages of having a comprehensive and reliable national climate monitoring system. On a national level, accurate weather forecasting is invaluable for many sectors, particularly agriculture. In developing countries, where the main economic activity of a majority of the population is linked to agriculture, predictions about what environmental conditions can be expected during the year can have a huge impact on people's livelihoods and the national food supply. Decisions about what crops to plant, when to plant and when to harvest are crucial and the more accurately weather can be forecasted, the better decisions can be taken (Box 4.3).

Box 4.3 Agricultural Climate Risk Zoning in Brazil

Since 1996, the Brazilian Ministry of Agriculture and EMBRAPA (Brazilian Enterprise for Agricultural Research) has coordinated the Agricultural Zoning Programme with the goal of increasing agricultural productivity by reducing agricultural losses due to incorrect sowing periods. In the State of São Paulo sowing periods for rice, beans, maize, soybean and wheat have been defined to minimise impacts from dry periods and high temperatures during the reproductive phase, very humid periods during harvest, and low temperatures during the cropping cycle. The planting periods were defined through the simulation of a climatic water balance that gives an index of water supply (ISNA) using historical rainfall data, potential evapo-transpiration, physiological characteristics of each crop, and water retention by the soil. The following results can be highlighted:

- Reduction of agricultural losses due to adverse climatic events
- Increasing productivity that in some cases can guarantee profits for the producer
- Availability of data that can be useful to help the official agricultural planning
- Reduction of official budget used to cover the agricultural losses is about US\$ 150 million per year.

Source: Zullo Jr et al, 2006

One of the effects of climate change seems to be the more frequent occurrence of extreme weather events. These include hurricanes and typhoons, as well as unseasonal extremes of temperature and heavy rains, which can cause droughts, flooding, landslides and other disasters. The devastation that these events can suddenly have on agricultural production means that any improvement on the ability to predict or anticipate them and plan accordingly is invaluable. Due to the complexity of global climate and weather systems and the fact that our understanding is based on modelling using historical data, the regular measurements of specific variables provided by climate monitoring systems is essential for developing early warning systems.

Disadvantages

The main disadvantage of a national climate monitoring system is the cost. Not just the capital required to purchase, install and/or operate all the necessary equipment, but also the ongoing costs of maintaining the equipment and ensuring accurate collecting of data, building and maintaining databases, making sure that that data is correctly interpreted and, ultimately, ensuring that relevant information is communicated to the appropriate people in a timely fashion. The quality of the information produced by a climate monitoring system is only as good as the quality of the data collected. Inaccurate data resulting from malfunctioning equipment, or gaps in coverage caused by lack of equipment, distort results and can lead to erroneous forecasting.

For many developing countries, insufficient resources are allocated to building and maintaining a national climate monitoring system. Also, due to the numerous pressing problems confronting many developing countries, there has often been a tendency for governments and policy makers to focus on short-term solutions to problems. In the case of most African countries, for example, climate is not systematically integrated into longer-term planning and investment decision-making.

Knowledge and Monitoring Requirements

Assessing the impacts of and vulnerability to climate change and subsequently working out adaptation needs depends on good quality information. Once information has been gathered, it must be analysed and fed into complex computer models in order to make predictions about future conditions. Maintaining a national climate monitoring system is a significant undertaking requiring a wide range of specially trained personnel. Local people can be trained to use equipment and to take accurate field measurements which can then be fed into the data base of the National Meteorological or Hydrometeorological Service. To process and analyse the raw data, however, requires numerous highly educated and experienced staff. In order to ensure sufficient coverage of data collection, measuring stations frequently need to be located in remote locations.

Institutional and Organisational Requirements

A national climate monitoring system is itself a network of regional and local monitoring resources, but the whole system must be managed and coordinated by the designated National Meteorological or Hydrometeorological Service (NMHS). The NMHS should also share climatic data readily with other relevant national and international organisations, as well as with researchers.

Costs and Financial Requirements

Financial requirements for establishing or improving a national climate monitoring system are considerable. The GCOS Regional Action Plans for ten developing regions of the world detail priority needs for

improvements in atmospheric, oceanic, and terrestrial observing systems totalling more than US\$ 200 million. Common needs include sustaining and improving operational observing networks; recovering historical data; and education, training, and capacity building. To boost weather and climate monitoring systems in Africa, the African Development Bank (AfDB) and the World Bank have agreed to provide 155 million dollars through the African Centre of Meteorology Applications for Development. In Cameroon, a National Observatory on Climate Change has been set up with US\$ 6 million of funding. The observatory is aimed at providing climate data monitoring the effects of climate change on the country's people, agriculture and ecosystems, and guiding work on climate action.⁶

Barriers to Implementation

The principal barriers to implementation are the financial and human resources required to set up and maintain a national monitoring system. The hardware, software and trained personnel needed are a big financial and time commitment. For many developing countries, other more pressing problems have a greater call on these resources.

Opportunities for Implementation

Part of the GCOS initiative is the GCOS Cooperation Mechanism (GCM). The GCM aims to develop a coordinated multi-governmental approach to address the high-priority needs for stable, long-term funding for key elements of global climate observing systems, especially those in developing countries. The GCM Donor Board has established appropriate procedures for developing funding proposals, manages the allocation of funds, monitors implementation activities and liaises with relevant national and international institutions and mechanisms. Features of the GCM funding mechanism include:

- Development of a critical mass of funding to support achievement of sustained improvements in global observing systems for climate
- Capability to address all types of funding requirements for global climate observations in developing countries, including system improvement, sustained operations, and capacity building
- Ability to develop, fund and implement cross-cutting approaches relevant to all climate disciplines/ regimes, including addressing data management and data exchange.

A Real Example of Application

Box 4.4 Climate Change Monitoring in Kenya

A sub-division of the Kenya Meteorological Department (KMD) is the Climate Change and Pollution Monitoring Services. The Division's main objective is extensive scientific research including monitoring, detection and assessment for climate change in the country; consistent with the regional/global issues of climate change. Expected results include:

- Climate change related products used in management, planning, and emergency preparedness
- Improvement in the capability of models used to project the future evolution of the climate system (i.e. ability of the models to simulate variability in the present and recent past)
- Capacity to: identify/understand impacts, vulnerability and adaptation, select and implement adaptation actions, and manage climate risks more effectively
- Enhance integration of climate change adaptation with sustainable development in the country.

The Division participates in national, regional and international climate change related initiatives and activities. These include the Inter-Governmental Panel on Climate Change (IPCC); United Nations Framework Convention on Climate Change (UNFCCC); preparation of the National Adaptation Programmes of Action (NAPA); Kenya Adaptation to Climate Change in Arid and Semi-Arid Lands (KACCAL); development of the National Climate Change Response Strategy (NCCRS); and development of the East African Community (EAC) Climate Change Master Plan.

In order to effectively cope with climate variability and change, the KMD has taken certain measures that will enable improvement in quality of service. These include:

- Issuing flood forecasts
- Research towards improvement of seasonal climate outlook predictions KMD hosts the Mt. Kenya Global Atmospheric Watch (GAW) Station. The goal of the GAW programme is to monitor, on a long-term basis the changing composition of atmospheric characteristics.

Source: Kenya Meteorological Department Website

4.1.2 Seasonal to Interannual Prediction

Definition

This technology allows for a forecast of weather conditions for a period of three to six months ahead. Seasonal forecasts are based on existing climate data; in particular, on sea surface temperatures, which are then used in ocean-atmosphere dynamic models, coupled with the synthesis of physically plausible national and international models⁷. Seasonal forecasts can be developed using mathematical models of the climate system (Alexandrov, 2006).

How the Technology Contributes to Climate Change Adaptation

According to the World Meteorological Organisation (WMO) definitions, Seasonal to Interannual Prediction (SIP) ranges from 30 days up to two years: monthly outlook, three-month outlook (description of averaged weather parameters expressed as a departure from climate values for that 90-day period) and seasonal outlook (WMO, 2010).

Modern and science-based systems facilitate seasonal forecasting. Predicting climate seasonal anomalies requires the use of complex coupled atmosphere-ocean models. It is believed that ocean variability is an important factor influencing climate variations and changes due to the ocean's larger capacity to absorb from and release heat back into the atmosphere. A considerable effort has been made to improve the understanding of the phenomena responsible for seasonal variability and most of the major meteorological institutions around the world have developed Ensemble Prediction Systems (EPS) for operational seasonal forecasting based on coupled atmosphere-ocean general circulation models (Grupo de Meteorología de Santander, 2010).

Climate change is challenging traditional knowledge about seasonal forecasting and farmers can no longer predict climate using natural indicators. According to Troccoli et al (2007), "(farmers)

Figure 4.1 WMO Global Producing Centres (GPCs) of Long Range Forecasts⁸

Source: WMO 2010 (www.wmo.int)

often have traditional ‘seasonal forecasting’ methods based on bird, animal and plant observations. However, while traditional practices may be resistant to change, experience often demonstrates farmers’ desires for ‘other’ knowledge systems that may be used alongside, and perhaps ultimately may displace, local practices” (Troccoli et al, 2007; 303). For instance, farmers in Burkina Faso have always used winter temperatures, the date and quantity of the first rains, and the special forecasting knowledge of diviners and religious leaders. However, they have admitted that traditional indicators are no longer working due to changes in the climate and so they welcome new information (Kirshen et al, 2003).

Advantages

Although knowledge and understanding of the socio-economic circumstances is important and must be taken into account, Meinke and Stone (2005; 221) have demonstrated how knowledge of climatic variability can lead to better decisions in agriculture, regardless of geographical location and socio-economic conditions. Within agricultural systems, this technology can increase preparedness and lead to better social, economic and environmental outcomes. It helps decision-making, from tactical crop management options, commodity marketing to policy decisions about future land use (idem).

According to their research, and based on a range of temporal and spatial scales, the types of agricultural decisions that could benefit from targeted climate forecasts are listed in Table 4.3.

Table 4.3 Agricultural Decisions and Climate Forecasts

Example of decision types	Frequency (years)
Logistics (e.g., scheduling of planting/harvest operations)	Intra-seasonal (<0.2)
Tactical crop management (e.g., fertiliser/pesticide use)	Intra-seasonal (0.2-0.5)
Crop type (e.g., wheat or chickpeas) or herd management	Seasonal (0.5-1.0)
Crop sequence (e.g., long or short fallows) or stocking rates	Inter-annual (0.5-2.0)
Crop rotations (e.g., winter or summer crops)	Annual/bi-annual (1-2)
Crop industry (e.g., grain or cotton; native or improved pastures)	Decadal (~10)
Agriculture industry (e.g., crops or pastures)	Inter-decadal (10-20)
Land use (e.g., agriculture or natural systems)	Multi-decadal (>20)
Land use and adaptation of current systems	Climate change

Source: Meinke and Stone, 2005; 230

Moreover, SIP is linked to a great variety of practical applications, from security related issues, such as water resource management, food security, and disaster forecasts and prevention; to health planning, agriculture management, energy supply and tourism. It is an important element in some policy/decision-making systems and is key to achieving the longer-term goals of climate change adaptation strategy (Troccoli et al, 2007). In Eastern Europe for instance, SIP is taken into consideration for the strengthening of drought preparedness and management, including drought contingency plans, at the local, national, sub-regional and regional levels (Alexandrov, 2006).

Disadvantages

When considering the limitations of this technology, it is worth mentioning that despite important achievements relating to adaptation strategies based on seasonal forecasting systems, significant levels of skill are generally only found in regions strongly connected with the El Niño Southern Oscillation (ENSO) (Arribas et al, 2009). This is a quasi-periodic, inter-annual variation in global atmospheric and oceanic circulation patterns that causes local, seasonal rainfall to vary at many locations throughout the world (Meinke and Stone, 2005; 228). In fact, ENSO forecasting is the main example of seasonal climate prediction which is why there is continuous improvement in the techniques involved. For example, the Met Office in the UK has developed a new seasonal forecasting system (GloSea4) that is flexible, easy to upgrade and enables improved forecasting over the El Niño regions.⁹

Knowledge and Monitoring Requirements

To use this tool effectively, Meinke and Stone suggest a participatory, cross-disciplinary research approach that brings together institutions (partnerships), disciplines (such as climate science, agricultural systems science, rural sociology, and many other disciplines) and people (scientists, policy makers and direct beneficiaries) as equal partners: “climate science can provide insights into climatic processes, agricultural

systems science can translate these insights into management options and rural sociology can help determine the options that are most feasible or desirable from a socio-economic perspective” (2005, 221).

The interpretation of the seasonal predictions of climate are not easy for most agricultural technicians and farmers to interpret as they are given as probabilities of positive or negative variations in temperature or precipitation. Although it must be recognised that all such predictions have an uncertainty associated with them, agricultural stakeholders need a lot of assistance as to how to identify the likely seasonal trends. Equally, meteorological services need staff with skills to present the information in a way that the public can interpret and make use of it.

Costs and Organisational Requirements

To implement this technology it is necessary to establish a meteorological service with skilled, trained and experienced personnel. This implies high costs if a country or region is starting from scratch, although these costs could be substantially reduced by using offices in public buildings and by partnering with scientific institutes and Global Producing Centres.

Barriers to Implementation

Access to forecasting (weather and seasonal) and climate information is common across most adaptation contexts. However, as with other interfaces between communities and experts, it will require investment in appropriate methods of communication and knowledge exchange (Ensor, 2009) such as targeted campaigns to promote the information usage and e-platforms promoted in local communities.

Making seasonal forecasting relevant to small-scale farmers and making sure the information reaches them represent the main challenges. For this reason, communication strategies are the key to using this technology effectively. Based on her experience in Lesotho, Ziervogel has pointed out that although seasonal climate forecast information is useful to some farmers, disseminating the information is a challenge. This is because it is often disseminated in English rather than Sesotho and via a press release that does not have the follow-up support that farmers would like. As a result, they are unable to examine the information in greater depth. This hampers discussion between farmers and experts as to what are the information needs and how it might be used (Ziervogel, 2007).

Kirshen et al (2003;4) have pointed to some specific communication challenges that need to be taken into account, based on lessons learned from climate change adaptation experience in West Africa:

- Distribution: there is not always equitable distribution of the forecasts to different village groups
- Measurements: farmers think in terms of crop production, livestock health, and water availability, not rain quantity
- Concepts: it is important to explain that a forecast is based on probabilities, not certainties and that it covers a specific region or area
- Media: most farmers can be reached by traditional media but they might have specific questions that need to be answered directly. The Climate Forecasting for Agricultural Resources (CFAR) project¹⁰ has run workshops in which ‘key’ farmers (i.e. those who interact a lot with other farmers) explain forecasts. These farmers then act as intermediaries to spread the forecast to other farmers in their villages.

Complementary approaches suggest that instead of replacing traditional farmers' forecasting, adaptation will be made easier if new forecasts are treated synergistically alongside traditional methods as a sympathetic way to introduce the use of new technologies (Troccoli et al, 2007; 303).

Opportunities for Implementation

As with most part of technologies applied at a national level, opportunities for implementation can be found where there is strong political will of implementing a national action plan to cope with climate change because of the type of investment required, and where communities work in vertical networks (with government and formal institutions).

Real Examples of Application

The National Meteorological and Hydrological Services (NMHS) of Bulgaria, Latvia, Serbia, Montenegro, Slovakia, Belarus, Armenia, Azerbaijan, Poland and Romania provide official SIP. In general, Eastern European countries tend to use SIP products supplied by global producers (Table 4.4).

Table 4.4 Countries Using SIP Products from Global Producers

Countries	Global Producers
Armenia, Azerbaijan, Belarus, Latvia	ROSHYDROMET
Slovakia, Greece	ECMWF products
Bulgaria	ECMWF, IRI, UK Met Office, Météo-France for a monthly weather forecast involving local weather and climate archive data downscaling
Lithuania	IRI, World Resources Institute and Swedish Regional Climate Modelling Programme
Poland	ECMWF, IRI, DWD
Romania	ECMWF, Met Office, IRI and Japan Meteorological Agency, among others

Source: Gocheva and Hechler, 2004

According to a survey conducted in 2004 (Gocheva and Hechler¹¹), while Russia, Croatia, Serbia, Montenegro and Slovakia partially used SIP in some sectors occasionally, Armenia, Belarus, Bulgaria, Kazakhstan, Latvia, Poland and Romania have a relatively broad SIP application in various sectors of the economy (such as energy generation and consumption, agriculture, disaster management, tourism and health, water management, transport and insurance).

There is no evaluation of specific benefits but in general, based on the Gocheva and Hechler survey, SIP was successful in ENSO related regions, but produced weak predictability in mid-latitudes (NAO) in Croatia, Poland and Romania. It seemed successful for specific regions and sectors in Bulgaria, Estonia, Slovenia and Cyprus, while in Armenia, Moldova and Kazakhstan it proved successful for a wide range of geographical regions.

Box 4.5 Seasonal Climate Forecasts in Lesotho

Agriculture supports the majority of the population in Lesotho. Farming is generally carried out on marginal land that is often steep, eroded, and infertile and has a highly variable climate. Seasonal climate forecasts are produced by the Lesotho Meteorological Service (LMS) and disseminated nationally. These forecasts provide information on rainfall expected during the rainy season and provide an important source of information to help farmers respond to climate variability. The accuracy of the forecasts varies, mainly due to the fact that Lesotho is a mountainous country where climate variability is high and difficult to predict. Nevertheless, farmers have reported using the information to invest in fertiliser if a good year is expected. Other ways of using the information have included making decisions about the type of crop to grow, how to manage water resources and how to allocate agricultural and household resources. The information has also enabled farmers to change planting and investment activities if a drought or good rains are forecast.

The Lesotho model has come across a number of significant dissemination and communication challenges that must be addressed in order to provide a more effective service to the country's farmers. These challenges provide useful insight to other governments that might want to implement this technology.

Challenges:

- Often the information is disseminated in English rather than Sesotho
- Late dissemination of forecasts leaves farmers with little time to make decisions
- Lack of personnel within the LMS, resulting in inadequate time dedicated to developing appropriate dissemination strategies, such as radio and print materials. Forecasts issued at national-level via a press release and expected to 'filter down' through the district level to the end-users. This is seldom carried out effectively due to weak coordination between state institutions, such as the Ministry of Agriculture and the District Agricultural Offices
- Extension agents not trained to communicate information effectively to farmers. Farmers have indicated a preference for receiving the information at community meetings from village chiefs
- No follow-up support is provided to farmers (from agents, input suppliers or other organisations) such as reducing the number of livestock, reducing the density of field crops, or planting more drought-resistant crops.

Source: Ziervogel, 2007; Ziervogel, 2001

Box 4.6 Seasonal Climate Forecasts in Burkina Faso

A distinctive rainfall gradient exists in Burkina Faso, from over 1,000 mm of rain in the Sudan climate south-west to as little as 100 mm on the boundary of the Sahel with the desert. Also there is considerable year-to-year variation in rainfall at one site ranging from only 400 mm in a drought year to 2000 mm in a heavy rainfall year. Obviously such differences greatly affect the productivity of agriculture and the decisions farmers need to make.

A project implemented by Tufts University and University of Georgia called 'Climate Forecasting for Agricultural Resources' looked to enhance access and capacity of farmers to use seasonal forecasts (Ingram et al, 2002). Interviews with farmers indicated that, in general, farmers were more interested in the timing of the onset and end of the rains, the likelihood of water deficits during the rains, and only lastly the total amount of rain. Nevertheless there were also differences between farmers. Cotton and maize farmers were interested in the onset of the rains for prepare for planting, and possible deficits when the maize is flowering. While in the more arid areas where sorghum and millet are grown they were interested in the quantity of rain to know whether to plant in low or high water retention areas, and which varieties to plant. Also most farmers agreed they needed the information one to two months before the onset of the rains to still have opportunity to adjust planting schedules and practices, look for seed of appropriate varieties, and prepare fields in appropriate locations.

In 1999 the seasonal forecast was announced on the radio in French, but at times farmers did not listen to the radio, and some would not understand. Some village agents received the forecast but did not understand it and so ignored it. In 2000 farmers were presented with a forecast in May that there was a 40 per cent probability of above normal rainfall, 40 per cent probability of normal rainfall, and 20 per cent probability of lower than normal rainfall. In general this agreed with farmers' impressions that rains would be higher than normal. To illustrate the nature of the probability 100 pieces of paper were put into a 'lottery draw' – 40 with more rain than normal, 40 normal rain and 20 less than normal. Farmers were then asked to pick out pieces of paper to demonstrate the degree of uncertainty as to the prediction.

In general it was considered that the forecast should be presented on the local radios in the local language, but ideally supported by extension agents who can help the interpretation. Even in 1999, the forecast encouraged farmers to continue planting even though the rains were due to start late, but were expected to be heavy rains. This led to the planting of an additional 50,000 hectares of cotton that was not planted at the time when the rains would normally have started. Meteorologists were concerned that farmers would take the predictions as a certainty and blame them if it was wrong. It was agreed that this should be emphasised in the forecasts, and that farmers were aware that different outcomes were possible and plan accordingly by diversifying their planting strategies. Also farmers complement the meteorological forecasts with their own knowledge and indicators of climate tendencies.

Farmers' strategies varied according to their main crops:

- Farmers in the south-west higher rainfall area indicated they would change the orientation of the furrows with furrows across slopes in dry years to retain water and down slope in wet years to shed water. If high rainfall is predicted farmers would plant rice that can withstand flooding. Or they plant maize if conditions are drier, or only plant maize or sesame in the higher areas. Also if low rainfall is predicted farmers would emphasise food crops over cash crops (cotton). There is also an interaction with labour availability if rains are heavy and weeds a problem they prefer to plant sorghum which is less susceptible to weeds than maize.

Contd...

- Farmers in the central plateau select the locations of fields to plant according to the climate. In drier years they will plant valley bottoms for which there is much competition, while in wetter years upland areas with shallow soils can be planted. In wet years the valleys can be planted with rice, with millet or maize on the higher ground. However maize requires more attention and manuring to produce. During the past 10-15 years farmers have changed from long-duration sorghum varieties (120-150 days) to short duration varieties (70-90 days), although the shorter period varieties need more weeding and better fertility to produce.

In general, farmers were very interested in receiving forecasts of climate, but their capacity to respond to information depended on how it was explained to them. It also depended on the resources and time they had to make adaptations to their planting systems. Fortunately there appears to be sufficient institutional capacity and local radio networks which most farmers listen to so that a seasonal weather forecast is viable to produce. Even more lacking are the extension services and resources to support the use of that knowledge.

Source: Ingram et al, 2002

In general, farmers were very interested in receiving forecasts of climate, but their capacity to respond to information depended on how it was explained to them. It also depended on the resources and time they had to make adaptations to their planting systems. Fortunately there appears to be sufficient institutional capacity and local radio networks which most farmers listen to so that a seasonal weather forecast is viable to produce. Even more lacking are the extension services and resources to support the use of that knowledge.

4.1.3 Decentralised Community-run Early Warning Systems

Definition

An Early Warning System (EWS) is a set of coordinated procedures through which information on foreseeable hazards is collected and processed to warn of the possible occurrence of a natural phenomenon that could cause disasters. These systems are acquiring more importance in view of increased climate variability and the ability to implement them has become fundamental for improving capacity to adapt to climate change.

Description and How it Contributes to Climate Change Adaptation

There are two types of EWS:

- **Centralised systems** implemented by national government bodies. The ministry of defence or another appropriate government entity is responsible for implementing hazard warning and response activities.
- **Decentralised community systems**, usually operated by a network of volunteers employing simple equipment to monitor meteorological conditions and operate radio communication networks.

Operators of decentralised community meteorological stations report the information to a local forecasting centre where the data is analysed and then communicated back to the community network. The demand for community-led systems is increasing due to lower operational costs and the need for local forecasting and monitoring of climate variability and potential disasters.

The following are the main implementation stages of a decentralised community system:

- Establishing an organising committee (leaders of the community and civil society, NGOs, representatives of local authorities and the private sector)
- Creating and analysing information: building and installing measuring instruments, carrying out forecasts
- Producing a participatory emergency and contingency plan
- Implementing a communication system: early warnings, dissemination of prevention, mitigation and adaptation measures.

Increased frequency and intensity of extreme weather events, prolonged drought and processes of desertification, longer periods of heavy rainfall and increased risk of flooding are just some of the impacts of climate change affecting the world's poorest populations (IPCC WG II, 2007). EWS technology designed as a climate change adaptation strategy must therefore be capable of forecasting a number of climatic events that correspond to different time scales:

- Three to four months of advance warning of a drought
- Two to three weeks of advance warning of freezing weather conditions and monsoons
- A few hours of advance warning of torrential rain, hail and floods.

This technology contributes to the climate change adaptation and risk reduction process by improving the capacity of communities to forecast, prepare for and respond to extreme weather events and thereby minimise damage to infrastructure and social and economic impacts, such as loss of livelihoods.

Advantages

Development benefits and other co-benefits provided by this technology include:

- Introduction of hazard-related and disaster management concepts into community-level planning processes
- Exchange of information of a social or legal nature, in addition to climatic information, through the established communication network
- Facilitation of decision-making in political organisations
- Creation and improvement of a structure that incorporates different stakeholders involved in drawing up specific action plans.

Disadvantages

The majority of EWSs were established to prevent or reduce the impacts of climate-related disasters (such as floods and hurricanes). By comparison, the capability of these systems to forecast droughts, extreme colds and Indian summers has been less effective. Droughts are particularly distinguishable from other extreme weather events in that they begin slowly and gradually and are less 'obvious' at the outset. In addition, drought can last extended periods of time and affect extensive areas. Given these complexities, EWS systems should be complemented with historical data on droughts, along with available climatological, hydrological, physical, biological and socioeconomic statistics. Only by combining this data can the complex causes of droughts be better understood and different scenarios modelled with the aim of developing prognoses (such as the probable start date of the rainy season or possible variations in rainy and dry seasons) to be disseminated via appropriate communication channels (Damman, 2008).

Knowledge and Monitoring Requirements

To implement a decentralised community EWS, monitoring and surveillance equipment is required. This implies handling real-time information and establishing regional and national mechanisms for exchanging technical/scientific information. Also required is the establishment of a system operating centre and communication system, as well as participatory planning of preparedness and response protocols.

Costs and Organisational Requirements

The initial implementation costs of a decentralised system comprised of ten local governments in one micro-water basin are estimated at US\$ 52,000 and annual operating costs are estimated at US\$ 25,000, as detailed below in Table 4.5.

Table 4.5 Indicative Costs for Implementation and Maintenance of Community Early Warning System

Implementation Costs			
Item	Unit	Cost (US\$)	Comments
Awareness-raising campaign including the involvement of authorities, institutions and the population		10,000	Workshops, printed material and radio broadcasts
Installation of a local weather station	10	5,000	1 station/district
Installation of limnimetric scales	10	2,000	1 scale/district
Creation and analysis of information: forecasting protocols	Study	10,000	1 study for all ten districts
Participatory production of the emergency and contingency plan	Study	10,000	1 study for all ten districts, including emergency drills
Implementation of a communication system: warning notices, mechanisms to disseminate prevention, mitigation and adaptation measures	Overall	5,000	Design of news bulletin and radio announcement formats and models, broadcasting via local networks
Training for local EWS operators and promoters	Overall	10,000	Around 20 people per district. Includes the production of training material
Annual Operating Costs			
Equipment maintenance		1,000	The sum includes basic maintenance of weather stations and limnimetric scales
Radio broadcasts		6,000	\$50/month per district
Dissemination of printed material		6,000	\$50/month per district
Communications		12,000	\$100/month per district

Source: Damman, 2008

Barriers to Implementation

The obstacles that could prevent the successful implementation and use of the technology are related to a number of factors. These include the population's lack of confidence in a new and unfamiliar system, problems with the dissemination of information to rural populations living in remote areas and the financial and management sustainability of the system.

Suggestions for overcoming these barriers, which have been tested in cases applied in Peru (Damman, 2008) include:

- Undertake a comprehensive awareness-raising and education plan amongst the population and participating institutions
- Ensure participation of the population and local institutions in the planning and implementation processes
- Incorporate local methods for disseminating information into the communication strategy
- Develop a network of local promoters linked to grassroots organisations for dissemination of information
- Develop sustainability and maintenance mechanisms, linking the EWS with local governments.

Opportunities for Implementation

The decentralised community system provides an opportunity for building awareness on climate change and disaster risk prevention approaches. It also provides opportunities for building capacity in decentralisation, participatory planning and budgeting processes whereby previously centralised roles are transferred to local governments and community stakeholders.

Case Study

In West Africa, the Red Cross has implemented The Early Warning and Early Action (EW/EA) framework in 14 countries. Key features of the EW/EA framework include disseminating appropriate information to communities using low-cost communication networks such as radio and telephone messaging (SMS); identifying the communities at risk and building dialogue with communities' leader/management structure; training local volunteers committees in translating meteorological information to communities into intelligible messages and actions; and linking early warning to action through contingency planning (Red Cross, 2010).

Between 2006 and 2007, Practical Action Latin America carried out three projects aimed at improving local disaster reduction and disaster management in the Piura, Apurímac and Cajamarca regions of Peru via the implementation of Community Early Warning Systems (Damman, 2008). The projects focused on: i) awareness raising around climate change, adaptation and risk management, ii) building capacity among key stakeholders – including community members and local authorities – for participatory planning and budgeting and iii) training community members in the installation and operation of decentralised EWS systems. In order to reach remote rural populations, networks of centres of information (InfoCentres) were set up with the participation of local promoters to coordinate dissemination of information via popular methods, including radio programmes, hard copy materials distributed at local markets and fairs, short television slots, and rural publications (newspapers, journals). The information systems established in these projects served agricultural adaptation by enabling the mapping of vulnerable zones and participatory land-use planning to be undertaken. By sharing these maps with local communities, the population was

able to identify a range of response mechanisms for different eventualities, for example selecting crops that would be planted in the event of a drought. The EWS information was also used to guide provision of technical assistance to farmers and install of demonstrative parcels where adaptation techniques could be observed and scientifically validated (Damman, 2008).

Box 4.7 Changing Time of Planting and Harvesting Based on Early Warning Systems

Weeks of planting (beginning of spring) and harvesting (end of autumn) can change with information coming from EWSs for farmers to plan different planting and harvesting weeks that coincide with new seasonal shifts. Farmers can also plant crops in cold winter months to avoid diseases (fungi and bacteria) and plagues (insects). They can use resistant varieties and sow them during the coldest months of the year when there is less rain. Diseases can be controlled using crop association.

Based on the genetic diversity of different varieties of crops, they can be sown in unfavourable micro-climatic conditions, using traditional varieties that are particularly resistant to frost and droughts. This is an advantage for dealing with extreme changes in weather conditions such as low temperatures or a limited supply of water. Genetic diversity reduces the risk of losing the total harvest and creates the right conditions to ensure a minimum production in order to overcome an adverse farming season (food security). Moreover, under good conditions, high productivity levels can be achieved.

Source: Prepared by the authors

4.1.4 Index-based Climate Insurance

Definition

Climate insurance against crop loss is common in developed country agriculture where farmers insure against crop loss due to extreme climatic events such as flooding or drought. Typically payments are made on the basis of the crop loss from on-farm inspections. However the on-farm inspections can be expensive and potentially subjective. Table 4.6 gives a summary of different kinds of agricultural climate insurance schemes. Index based climate insurance uses models of how climate extremes affect crop production to determine certain climate triggers that if surpassed cause substantial crop loss and would support a compensation payment. This has the advantage of being totally objective and not requiring on-site inspection. The US Federal Crop Insurance Plan has offered this kind of insurance since the 1990s.

Table 4.6 Summary of Climate Insurance Products for Agriculture

Insurance Product	Basis	Applicability	Successful Examples
Named Risk Climate Insurance	Insurance against loss for specific event, for specific amount, loss verified in the field	Example: hail insurance that causes a specific catastrophic loss that can immediately be identified in the field	All continents, especially USA and Canada
Multiple Risk Climate Insurance	Insurance against yield loss below 50-70 per cent of expected yield due to any cause	High costs, and requires verification in the field of actual yields	All continents, especially USA and Canada

Contd...

Insurance Product	Basis	Applicability	Successful Examples
Area/Yield Index Insurance	Insured against yield loss below a certain per cent across a district. Yield changes verified independently on a sample of farms across the district	Suitable for losses from drought, lower costs as not verified on each farm, but assumes same average effect across all farms in a district	Brazil, India, USA
Climate Weighted Index Insurance	Insurance based on certain climatic conditions being met. If met certain loss of production assumed and compensated for	Allows large number of small holdings to be aggregated in a uniform area. Low cost as no verification, but high cost of development of models, and meteorological monitoring	India, Malawi, Mexico, Canada, USA
Normalised Difference Vegetation Index	Based on satellite monitoring of vegetation development	Mainly applicable to grazing lands	Mexico, Spain, Canada
Livestock Mortality Index	Based on independent estimates of livestock mortality rates	Managed communally or through NGOs	Mongolia
Flood Insurance	Traditionally based on individual verification of areas flooded and damage incurred. Exploring index based systems based on satellite monitoring of area and number of days flooded versus crop losses	Requires prior registration of areas under different land-uses by farmers. Risk levels vary considerably over small geographic distances	Index based insurance under investigation in South East Asia

Source: Derived from a presentation by P Valdivia 2010

Description and How it Contributes to Climate Change Adaptation

Crop losses in years of extreme climatic events can cause extreme hardship on farmers. It can force them into debt, leading them to sell their assets, even their land, and preventing them from being able to invest in the following year's production. These events are considered to be a considerable cause of why resource poor farmers are unable to accumulate sufficient goods and capital to rise out of poverty. With climate change it is expected that extreme climatic events are likely to become more frequent and thus their impacts on the livelihoods of farmers. Almost all farmers have traditional coping mechanisms for surviving periods of drought, such as selling livestock and temporary migration to sell their labour. However, these mechanisms may not be able buffer the impacts of extreme events, or droughts lasting more than one season. Therefore it is critical to find financial mechanisms to support farmers in years of financial loss due to climatic events. Also if such losses become more frequent then farmers will be less willing to take out credit, and lenders may be less willing to lend (or increase the costs of lending) due to the higher risks involved. If farmers do not have access to credit then this severely limits their capacity to invest in improving productivity and profitability of the agricultural livelihood.

Advantages

The insurance costs are reduced as no in-situ verifications are made of actual losses. This makes it viable to provide coverage to a large number of small-scale producers for whom it would be unviable to provide standard insurance. The insurance is most easily administered as part of other financial services to farmers, principally credit, and the insurance can be against not being able to pay back the credit in event of losses due to extreme climatic events. This would reduce the risk of farmers losing their land or other assets due to climatic extremes.

Disadvantages

Index based insurance requires significant capacity for analysis of weather related risk to design the index, good historical weather records, and extensive network of weather stations for monitoring current climate. Another disadvantage is that as payments are connected to the climate surpassing a certain trigger, if crop losses occur without passing this trigger then no payment will be made. Or conversely, if the trigger is passed, payment will be received even if no losses have occurred. This is a cost of not having any in-situ inspection. However, it runs the risk of farmers' expectations of compensation not being met, and doubting the value of the insurance.

Knowledge and Monitoring Requirements

The design of index based climate insurance requires two basic information sets.

- Historical data of climate conditions and crop productivity to evaluate the production risk and trigger for substantial crop loss, and the associated economic risk and thus price required for the product
- Real-time weather data with a significant geographic coverage to evaluate whether the climatic trigger has been surpassed and payment should be made.

Costs and Organisational Requirements

Costs of Development

The development of indexed linked climate insurance as a commercial product has generally involved the collaboration between interested insurance companies (whether public or private) and facilitated by national or multi-lateral organisations such as the World Bank or regional development banks who have subsidised the costs of development of climate insurance products. Many NGOs have also developed interest in these products, such as Oxfam. It seems clear that a private insurance company on its own is unlikely to develop climate insurance products. Usually, climate insurance is developed through some kind of public-private partnership.

Even after a product has been developed, substantial investment needs to be made to explain the product to farmers or their representatives. One essential aspect is educating farmers to understand the product and not create false expectations about what it offers, but not reinforce the mistrust that many farmers have of these kinds of product.

Cost to Farmers

Normally farmers would pay for the insurance, either directly or more commonly as an additional financial service associated with a loan. In some cases the costs of insurance are subsidised by the government, where it is considered strategic for the country to support buffering the impacts of climate change. Some countries such as Mexico, Peru and Brazil subsidise the insurance premium. Other countries may participate in the re-insuring of the initial insurance which also reduces the costs of the premium.

Barriers to Implementation

One of the major barriers to implementation is the need to re-insure the climate insurance provided by insurance companies. This is necessary as an extreme weather event normally covers a substantial proportion of many countries and there may be limited economic capacity to meet all the claims resulting from the event. Nevertheless, achieving re-insurance requires a solid financial model to convince these companies to assume this risk at a reasonable price. Again public participation in these schemes, whether from national or multi-lateral bodies (who would often have to cover the costs of recovery from natural disasters anyway) can reduce the costs of re-insurance or make it more acceptable to the international insurance industry.

Opportunities for Implementation

The World Bank has supported the design and piloting of climate insurance schemes in many countries across the world. So have other development agencies such as USAID, DFID and the regional development banks. Nevertheless, most of the initiatives have also required the support from national governments, and technical support financed by external agencies. Most farmers are not accustomed to insurance and in many cases do not have a good understanding of the nature of the product or the probabilities of it compensating for any loss. The success of such schemes offered directly to farmers hinges on considerable investments in raising farmers' awareness about financial risk management. Fortunately considerable expertise has now been developed. One of the primary tools is using games to illustrate the different insurance packages and the scenarios under which they may compensate and those situations where they do not. There is reason to believe that such games substantially increase farmers' understanding of the insurance and their willingness to participate (Patt et al, 2010).

Real Examples of Application

Box 4.8 ENSO Insurance in Peru

El Niño events in the southern Pacific cause well known effects in regional and global climate. In coastal Peru the impacts of an El Niño – the warming of the ocean off the coast are highly predictable in terms of cause very high rainfall leading to catastrophic flooding. When an El Niño event is known to be initiating, farmers in the Piura district abandon the sowing of crops, which in turn lead to fall in income and sales across all households. In 1998 agricultural debt increased by 10 percentage points during the El Niño event. In the following five years, the demand for agricultural loans stagnated and did not resume growth until families had recovered sufficiently to increase borrowing again.

Due to this situation index-based climate insurance was developed that insured an amount based on a prior risk assessment of the maximum potential loss (Skees, 2010). Payment is triggered when sea temperatures rise above 24.5 °C in November-December as indicated by NOAA, the independent US based Climate Prediction Centre. Payments are made in January, prior to the expected flooding in February-March. This enables funds to be used to prepare for the disaster, and workshops are conducted to help organisations decide how to use the funds in a preventative way. In one case a farmers' association used the funds to clear the causeway that would take the flood waters.

The product is re-insured to international re-insurance companies, as all sectors are likely to be affected by such catastrophic events, and thus a local insurer would not have the capacity to pay out. Nevertheless, the product is only available to risk aggregators, such micro-finance agencies or farmer associations, and not directly to small-holders.

Source: Skees, 2010

Box 4.9 Insurance against Additional Costs of Irrigating Coffee in Vietnam

In the central highlands of Vietnam, smallholder coffee farmers are exposed to drought. When drought occurs, these farmers often manage yield losses by increasing irrigation. However, when they extend the irrigation season, they also incur significantly higher costs as the water table is depleted and irrigation becomes more expensive. Some coffee plants also suffer from lower amounts of water resulting in coffee beans that are perhaps one-third the size of normal beans. Prices can fall to less than half what they would be under normal weather conditions. In the worst conditions, coffee trees die. In a pilot project supported by the Ford Foundation, the Vietnam insurance regulator has approved a drought business interruption insurance product designed to compensate for the consequential losses associated with severe drought conditions. This insurance pays the farmers the cost of the additional irrigation to prevent the loss in yield. A traditional crop insurance product would only pay for crop-yield losses and would not be interesting to these growers.

Source: Skees, 2010

Box 4.10 Indexed Livestock Mortality Insurance in Mongolia

An index-based livestock insurance programme in Mongolia was designed in the context of a World Bank lending operation with the Government of Mongolia and implemented on a pilot basis in 2005. This project offered the first opportunity to design and implement an agriculture insurance programme using a country-wide agricultural risk management approach. Livestock losses can be severe during periods of drought and extreme cold, known as dzuds. During such a period between 1999 and 2002 a third of the national herd was lost, as livestock production represents 61 per cent of GDP. This had significant national economic consequences. The insurance programme involves a combination of self-insurance by herders, market-based insurance, and social insurance. Herders retain small losses, larger losses are transferred to the private insurance industry, and extreme or catastrophic losses are transferred to the government using a public safety net programme. The fiscal exposure of the Government of Mongolia toward the most extreme losses is protected with a contingent credit facility with the World Bank. The insurance programme relies on a mortality rate index by species in each local region. Data exists for 33 years of the mortality rates of the five main livestock species which provides the basis for the estimate of risk of losses by district and by species, but also an existing system to monitor overall mortality rates. The index provides strong incentives to individual herders to continue to manage their herds so as to minimise the impacts of major livestock mortality events; individual herders receive an insurance payout based on the local mortality, irrespective of their individual losses. Insurance premiums are differentiated by district and by species. During the first sales season, 9 per cent of the herders, in the three pilot regions, in total purchased the insurance product covering 300,000 head for a value of \$78,000. The majority chose coverage that paid 30 per cent of the value of losses when mortality was over 10 per cent. Higher recovery or lower mortality packages were not so popular due to the higher premiums. Also local lenders, at their own initiative offered credit at lower rates to those that purchased insurance.

Source: Mahul and Skees, 2007

Box 4.11 Fondos in Mexico

Fondos are self-insurance funds that have been operating in Mexico since 1988 (Ibarra and Mahul, 2004). In 2004, more than 240 Fondos provided insurance against agricultural production risks (including hail, drought, frost, floods, diseases, and pests) to their members, accounting for 50 per cent of the total insured agricultural area in Mexico. The total liability of the Fondos on an annual basis was approximately US\$ 400 million in 2004. They are concentrated in agricultural areas with productive potential and financial viability. Subsistence and poor non-commercial farmers are supposed to be covered through the government-sponsored national disaster scheme FONDEN.

Fondos are non-profit organisations constituted by the farmers. According to Mexican laws, to establish Fondos, farmers only need to indicate their willingness to associate between themselves, and there is no requirement for providing capital endowment. From a risk-financing perspective, Fondos pool crop yield risks from farmers with similar risk profiles. The concept of insurance through mutuality-type organisations was developed in Mexico based on a sound insurance market approach, while taking advantage of mutuality-type organisational principles and a structure of incentives to keep transaction costs under control. The Fondos cannot sell insurance to their members unless they have a proper reinsurance treaty negotiated before the beginning of any specific agricultural cycle of production. Since these organisations do not have the capital to guarantee the solvency of the Fondos, they must buy enough reinsurance to guarantee that the members of the Fondo will receive the full amount of indemnity in the case of a peril (no default risk). The regulation requires that any reinsurance contract negotiated by the Fondos should be defined to absorb any exceeding indemnities after the financial reserves of the Fondos have been exhausted. Therefore, an unlimited stop-loss reinsurance treaty is implicitly requested. Historically, the state-owned reinsurance company Agroasemex has offered to the Fondos this unlimited stop loss programme. The Government also supports a training programme to enhance the operations of the funds through Agroasemex. The training programme includes technical aspects related to the underwriting and loss adjustment procedures, the development of new products, accounting, legal aspects and so on.

Since 2003 the Government of Mexico, has been operating the drought disaster relief response budgets of federal and the state governments by offering rainfall index-based insurance products through its government-owned reinsurance company. The programme was launched to address, among other things, financial disruptions to other government programmes to fund emergency responses as a result of weather shocks. In 2007 approximately 1,900,000 hectares were insured against drought. The risk was transferred to the international weather market through 230 weather stations for a sum insured of US\$ 90 million at a premium of US\$ 9.7 million. The programme was successfully tested in 2005 by a US\$10.5 million payout triggered by severe drought in several states (Agroasemex, 2006).

Source: Agroasemex, 2006; Ibarra and Mahul, 2004

4.2 Technologies for Sustainable Water Use and Management

The Intergovernmental Panel on Climate Change (IPCC WG II, 2007) predicts that during the next decades, billions of people, particularly those in developing countries, will face changes in rainfall patterns that will contribute to severe freshwater shortages or flooding resulting in negative impacts on agricultural production (IPCC WG II, 2007). Some studies suggest that by 2025, more than a third of the world population will face

absolute water scarcity (Seckler et al, 1998; Seckler et al, 1999; Rosegrant et al, 2002). Enhancing water availability through adaptation technologies for sustainable water use and management is therefore a key strategy for increasing agricultural productivity and securing food security in these regions.

4.2.1. Sprinkler and Drip Irrigation

Sprinkler Irrigation

Definition

Systems of pressurised irrigation, sprinkler or drip, can improve water efficiency and contribute substantially to improved food production. Sprinkler irrigation is a type of pressurised irrigation that consists of applying water to the soil surface using mechanical and hydraulic devices that simulate natural rainfall (see Figure 4.2). These devices replenish the water consumed by crops or provide water required for softening the soil to make it workable for agricultural activities. The goal of irrigation is to supply each plant with just the right amount of water it needs. Sprinkler irrigation is method by which water is distributed from overhead by high-pressure sprinklers, sprays or guns mounted on risers or moving platforms. Today a variety of sprinkler systems ranging from simple hand-move to large self-propelled systems are used worldwide. Global use of sprinkler irrigation is: the Americas (13.3 million hectares (Mha)), Europe (10.1 Mha), Asia (6.8 Mha), Africa (1.9 Mha), and Oceania (0.9 Mha) (Kulkarni et al, 2006).

Figure 4.2 Farmland Sprinkler System in Cajamarca, Peru



Source: Courtesy of David Dennis Rabines Alarcon

Description

A sprinkler irrigation system typically consists of:

- A pump unit which takes water from the source and provides pressure for delivery into the pipe system. The pump must be set to supply water at an adequate pressure so that the water is applied at rate and volume adequate to the crop and soil types
- Main pipes and secondary pipes which deliver water from the pump to the laterals. In some cases these pipelines are permanently installed on the soil surface or buried below ground. In other cases they are temporary, and can be moved from field to field. The main pipe materials used include asbestos cement, plastic or aluminium alloy
- The laterals deliver water from the pipes to the sprinklers. They can be permanent but more often they are portable and made of aluminium alloy or plastic so that they can be moved easily
- Sprinklers, water-emitting devices which convert the water jet into droplets. The distribution of sprinklers should be arranged so as to wet the soil surface in the plot as evenly as possible
- A wide range of sprinkler systems is available for small and large-scale application. Set systems operate with sprinklers in a fixed position. These sprinklers can be moved to water different areas of the field, either by hand or with machinery. Hand-move systems are more labour intensive and may be more suited where labour is available and cheap. On the other hand, mechanically operated systems require a greater capital investment in equipment. Mobile systems minimise labour inputs by operating with motorised laterals or sprinklers, which irrigate and move continuously at the same time (Savva and Frenken, 2002)
- Sprinkler irrigation efficiency is highly dependent on climatic conditions. FAO (1982) proposed the figures of farm irrigation efficiencies provided in Table 4.7 on the basis of climate.

Table 4.7 Efficiencies for Sprinkler Irrigation in Different Climates

Climate/Temperature	Farm Irrigation Efficiency ¹²
Cool	0.80
Moderate	0.75
Hot	0.70
Desert	0.65

Source: adapted from FAO, 1982

How the technology contributes to climate change adaptation

Sprinkler irrigation technology can support farmers to adapt to climate change by making more efficient use of their water supply. This is particularly appropriate where there is (or is expected to be) limited or irregular water supply for agricultural use. The sprinkler technology uses less water than irrigation by gravity, and provides a more even application of water to the cultivated plot. Additionally, sprinkler irrigation can reduce the risk of crops freezing due to colder than usual temperatures. More frequent and intense frosts are already impacting on crops as a result of climate change. During the night, the motion of the sprinklers and the application of rain-like water droplets can reduce the stress on crops caused by a sharp decrease in temperature (Snyder and Melo-Abreu, 2005).

Advantages

One of the main advantages of the sprinkler irrigation technology is more efficient use of water for irrigation in agriculture. Sprinkler systems eliminate water conveyance channels, thereby reducing water loss. Water is also distributed more evenly across crops helping to avoid wastage. The sprinkler irrigation system has also been shown to increased crop yields (Table 4.8) and is suited for most row, field and tree crops that are grown closely together, such as cereals, pulses, wheat, sugarcane, groundnut, cotton, vegetables, fruits, flowers, spices and condiments (Narayanmoorthy, no date) and for cultivating paddy crop (Kundu et al, 1998).

Table 4.8 Response of Different Crops to Sprinkler Irrigation Systems

	Water Saving, %	Yield increase, %
Barley	56	16
Cabbage	40	3
Cauliflower	35	12
Chillies	33	24
Cotton	36	50
Groundnut	20	40
Maize	41	36
Onion	33	23
Potato	46	4
Wheat	35	24

Source: adapted from INCID (1998), Table 6.5.

Sprinkler irrigation technology is well adapted to a range of topographies and is suitable in all types of soil, except heavy clay. Sprinkler systems can be installed in either permanent or mobile modes. Sprinklers provide a more even application of water to agricultural land, promoting steady crop growth. Likewise, soluble fertilisers can be channelled through the system for easy and even application. The risk of soil erosion can be reduced because the sprinkler system limits soil disturbance, which can occur when using irrigation by gravity. In addition, sprinkler irrigation can provide additional protection for plants against freezing at low temperatures. Secondary benefits from improved crop productivity include income generation, employment opportunities and food security.

Disadvantages

The main disadvantages associated with sprinkler systems are related to climatic conditions, water resources and cost. Even moderate winds can seriously reduce the effectiveness of sprinkler systems by altering the distribution pattern of the water droplets. Likewise, when operating under high temperatures, water can evaporate at a fast rate reducing the effectiveness of the irrigation. Although sprinkler irrigation can help farmers to use water resources more efficiently, this technology relies on a clean source of water and therefore may not be suited to areas where rainfall is becoming less predictable. Implementation

costs are higher than that of gravity-fed irrigation systems and large labour force is needed to move pipes and sprinklers in a non-permanent system. In some places such labour may not be available and may also be costly. Mechanised sprinkler irrigation systems have a relatively high energy demand (Savva and Frenken, 2002).

Knowledge and Monitoring Requirements

When planning to install a sprinkler irrigation system, information should be obtained regarding the following key factors:

- The crop or crops to be cultivated and their water requirements throughout the growing season
- The shape and size of the field. This will determine the range of suitable technologies, investment and labour requirements
- Topography, in particular the location and elevation of the water source relative to the field, land slopes and uniformity
- The water source. The source of irrigation water can be surface water, groundwater or non-conventional water (such as desalinated water and treated wastewater) (Savva and Frenken, 2002). Water must be available in sufficient quantity from a locally accessible source. A clean supply of water free of sediment is required to avoid blockage in sprinkler nozzles and crop spoilage (FAO, 1988)
- Available labour force. Where skilled labourers are not available on location, local farmers will require training to install, maintain and repair the various components of the sprinkler system
- The soil profile. Sprinkler irrigation technology is best suited to soils with high infiltration rates so that ponding and surface runoff can be avoided. The application rate of the sprinkler system must therefore be matched to the infiltration rate of the most restrictive soil in the field
- Energy requirements of different systems, including the manufacturing, transportation and installation of the various systems. The location of the water source will also affect the need for energy for pumping (Savva and Frenken, 2002)
- Social aspects such as local preferences, capacity to maintain the system, implications for labour requirements and how these may affect different members of the community (Savva and Frenken, 2002)
- An understanding of existing health risks is crucial to avoid schemes that may promote water borne diseases (Savva and Frenken, 2002)
- An environmental impact assessment should be conducted to fully understand potential impacts of drainage and diverting water resources, amongst others (Savva and Frenken, 2002).

Maintenance of the system mainly relates to regular cleaning of the component parts. Seals on pipes and sprinkler nozzles should be checked to avoid water seepage. During periods when the equipment is not being used, it is recommended to store component parts in a cool, dark place.

Costs and Financial Arrangements

The cost of installing a sprinkler system suitable for a family production unit ranges from US\$ 600 to US\$ 2500 per hectare, depending on the type of materials used and the amount of labour contributed by rural producers. Affordable Micro Irrigation Technologies (AMITs) are low cost and low pressure systems with the same technical advantages as conventional micro-irrigation system, however the technology is packaged and marketed as kits suitable for small fields (25 m² to 4000 m²). The AMIT has the specific advantage of being affordable, and easy to understand; they also have rapid pay back, divisibility and expandability.

Institutional and Organisational Requirements

According to Savva and Frenken (2002), a whole range of institutional conditions must be understood before sprinkler irrigation technology selection can be made. These include land tenure issues, water rights, and financial incentives by government and taxation. Large-scale irrigation schemes will usually form part of national policy and could be harnessed to support national employment initiatives. Where the sprinkler irrigation type is not available nationally, foreign imports or government-supported stimulation of national manufacture will be required alongside investment in training for design, installation and maintenance. Coordination with public or private authorities in charge of water management will be crucial and could be facilitated through the establishment of a committee of irrigation users. At a local level, social organisation for the participatory monitoring of water resources and quality could provide a key monitoring tool. Whichever method is selected, developing regulations for the distribution and allocation of water would provide an important mechanism for conflict resolution.

Whether a large or small-scale intervention, farmer involvement in the development stages of a sprinkler irrigation project is recommended to help ensure social acceptance and technical success (Box 4.12).

Box 4.12 Sprinkler Irrigation in Zimbabwe

“The Hama Mavhaire irrigation scheme in Zimbabwe is a 96 hectare drag-hose sprinkler irrigation project. The scheme is apportioned equally to 96 farmers, of which 70 per cent are women. It is located in a dry agro-ecological area that receives about 450 mm of rainfall per year. Dryland cropping fails 3 to 4 years out of 5. The development of the scheme was initiated in 1989, following strong farmer requests to the government for irrigation development.

Participation of Farmers in Planning and Design

The government dispatched a team of experts, comprising engineers, agronomists and economists, to the project site to carry out a feasibility study. Several meetings were held in order for planners to understand the farmers’ expectations and to explain to the farmers the potential of and requirements for the proposed development. This was followed by a baseline socio-economic survey. The land chosen consisted of about 80 per cent of non-cultivated bush, while the remaining 20 per cent was arable land owned by the farmers who were selected for the scheme. The farmer group was to be the partner in irrigation development. It elected its own committee, which was tasked with liaising with the planners on all matters related to the new development.

To facilitate a process of making informed decisions, arrangements were made for farmers to visit different types of irrigation systems, surface and sprinkler. This exposure proved useful to farmers when they eventually decided on the type of irrigation system they preferred and the crops to be grown. This process took one full year.

Participation of Farmers in Construction

When the design was adopted, tender documents were written to include the condition that the farmers would provide all unskilled labour required for construction. During construction the group provided labour for trenching and back-filling and assisted pipe fitters by carrying and placing pipes and fittings in position. As a result of their participation, the farmers were trained in pipefitting and other general repairs to their system. Additionally, the contractor trained one farmer per irrigation block on the repair of sprinklers. The irrigation engineers and extension staff trained the farmers in leadership, bookkeeping, scheme operation, improved agronomic practices and irrigation scheduling. This process took six months for the first 48 hectares and three months for the remaining 48 hectares.

Contd...

Socio-economic Impact of Scheme Development

On average, the net income per plot-holder quadrupled due to the introduction of irrigation, from a gross margin assessed at US\$ 650 annually on 2.5 hectares of dryland crop production to a gross margin of US\$ 2,775 for one hectare irrigated. There are other indicators of a substantial rise in the standard of living of the irrigators. About 29 per cent of the plot-holders are reported to have purchased between one and four head of cattle from the income earned through irrigation during the first five to six years of scheme operation. In addition, 13 per cent of the plot-holders had put up brick under corrugated iron houses and 10 per cent had installed solar panels during the same period. Women, who constitute the majority of the plot-holders and are represented at all committees, also confirmed that the other major benefit of irrigation was that they are able to pay for the costs of educating their children.

The success of the Hama Mavhaire irrigation scheme is largely attributed to the participatory approaches adopted for the development of the scheme provided the opportunity to the group, planners and implementers to jointly plan and implement a scheme, making it both technically feasible and socially acceptable.”

Source: Savva and Frenken, 2002

Barriers to Implementation

Possible barriers to implementation include lack of access to finance for the purchase of equipment, lack of local skills for design, installation and maintenance of the system and lack of nationally/locally available component parts. A low level of public awareness of or concern for the importance of sustainable water management and use could also be a barrier to the exploration of sprinkler irrigation technology as a climate change adaptation option.

Sprinkler irrigation requires a suitable source of fresh water to be identified in close enough proximity to the farmland. This ensures that costs are kept at a reasonable level. Water availability will be highly dependent not only on current resources but also on future climate conditions. Where knowledge of potential climate change impacts on water resources does not exist, installing a sprinkler irrigation system could lead to conflicts over local water use.

Opportunities for Implementation

Sprinkler irrigation is a versatile technology suitable for application in a wide range of contexts, can be implemented at small or large scale and with either low-cost or more sophisticated components. This technology can be employed in conjunction with other adaptation measures such as the establishment of water user boards, multi-cropping and fertiliser management.

A Real Example of Application

The ‘Integrated Development Project for the Promotion of Sustainable Livelihoods and Poverty Reduction in the Rising Llaucano Basin’ (Yachan Project, Fuertes and Bonfiglio, 2008) carried out activities in 22 villages in the districts of La Encañada and Bambamarca, in the province and region of Cajamarca in Peru. The purpose of the activities was to contribute to building and strengthening the livelihoods of farmers in the upper basin of Llaucano. This was done principally through creating new agricultural infrastructure, constructing and/or improving sprinkler and gravity irrigation systems, increasing the technological capabilities of the population, strengthening local organisations and providing agricultural outreach

services. The target population were rural farmers living in poverty and unable to satisfy basic needs for food, clean water, education, health, sanitation and lighting. The population's main activity is small-scale farming on land between 3,000 and 3,800 metres above sea level, in an environment exposed to frost, hailstorms and drought. Consequently, most of the area is allocated to natural pasture and, to a lesser extent, to cultivated pasture and other cultivated crops such as potato, oca, root vegetables, beans and peas, the latter mainly for self-consumption.

Most revenue is generated from the sale of milk to two wholesalers and to small producers of petit-cheese (quesillo) and cheese. A substantial part of the investment went to the installation of sprinkler irrigation and the improvement or construction of irrigation canals, mainly used for the irrigation of new forage species, and thus directly influencing milk production. After four years of project intervention the following impacts were achieved:

- 1,042 families benefited from the installation of sprinkler systems that allowed an area of 944 hectares to be supplied with water
- To date, 430 hectares have been sown with new forage species that enable higher production yields and an increase in the amount of food for livestock
- The technology package for the cultivation of grasses grown under irrigation has resulted in a 145 per cent average increase in yield per hectare. This information is derived from sampling 46 plots in the project area
- Sprinkler irrigation and improved pastures achieved an annual production of 202 metric tons per hectare, at a cost of US\$ 618 per hectare. This production cost is much cheaper than the market price of pasture
- The project has led to the creation and strengthening of development committees in each village and irrigation committees of water users who manage, operate and efficiently maintain their irrigation systems.

Technology: Drip Irrigation

Definition

Drip irrigation is based on the constant application of a specific and calculated quantity of water to soil crops. The system uses pipes, valves and small drippers or emitters transporting water from the sources (i.e. wells, tanks and or reservoirs) to the root area and applying it under particular quantity and pressure specifications. The system should maintain adequate levels of soil moisture in the rooting areas, fostering the best use of available nutrients and a suitable environment for healthy plant roots systems. Managing the exact (or almost) moisture requirement for each plant, the system significantly reduces water wastage and promotes efficient use. Compared to surface irrigation, which can provide 60 per cent water-use efficiency and sprinklers systems which can provide 75 per cent efficiency, drip irrigation can provide as much as 90 per cent water-use efficiency (Tanjil and Kielen, 2002). In recent times, drip irrigation technology has received particular attention from farmers, as water needs for agricultural uses have increased and available resources have diminished. In particular, drip irrigation has been applied in arid and semi-arid zones as well as in areas with irregular flows of water (or in zones with underground water resources that rely on seasonal patterns such as river-flow or rainfall).

Figure 4.3 Drip Irrigation System for an Olives Tree farm in Ica Valley, Peru



Source: Courtesy of Rafael Galván, Farm Manager Agriver SAC (2011)

Description

A drip irrigation system typically consists of:

- Pumps or pressurised water system
- Filtration systems
- Nutrients application system
- Backwash Controller
- Pressure Control Valve (Pressure Regulator)
- Pipes (including main pipe line and tubes)
- Control Valves and Safety Valves
- Poly fittings and Accessories (to make connections)
- Emitters.

A wide range of components and system design options is available. Drip tape varies greatly in its specifications, depending on the manufacturer and its use. The wetting pattern of water in the soil from the drip irrigation tape must reach plant roots. Emitter spacing depends on the crop root system and soil properties. Drip irrigation zones can be identified based on factors such as topography, field length, soil texture, optimal tape run length, and filter capacity. Many irrigation system suppliers use computer

programmes to analyse these factors and design drip systems. Once the zones are assigned and the drip system is designed, it is possible to schedule irrigations to meet the unique needs of the crop in each zone. Recent automatic systems technology has been particularly useful to help control flows and pressure, and to identify potential leaks thereby reducing labor requirements. System design must take into account the effect of the land topography on water pressure and flow requirements. A plan for water distribution uniformity should be made by carefully considering the tape, irrigation lengths, topography, and the need for periodic flushing of the tape. The design should also include vacuum relief valves into the system. Figure 4.5 shows a drip irrigation system for capers filed in Peru.

Figure 4.4 Capers Field under Drip Irrigation System in Sandy Soil Pisco Valley Peru



Source: Courtesy of Rafael Galván, Farm Manager Agriver SAC (2011)

How the Technology Contributes to Climate Change Adaptation

Drip irrigation technology can support farmers to adapt to climate change by providing efficient use of water supply. Particularly in areas subject to climate change impacts such as seasonal droughts, drip irrigation reduces demand for water and reduces water evaporation losses (as evaporation increases at higher temperatures). Scheduled water application will provide the necessary water resources direct to the plant when required. Furthermore, fertiliser application is more efficient since it can be applied directly through the pipes. As is the case with a sprinkler system, drip irrigation is more appropriate where there is (or is expected to be) limited or irregular water supply for agricultural use. However, the drip technology uses even less water than sprinkler irrigation, since water can be applied directly to the crops according to plant requirements. Furthermore, the drip system is not affected by wind or rain (as is the sprinkler technology).

Advantages

Drip irrigation can help use water efficiently. A well-designed drip irrigation system reduces water run-off through deep percolation or evaporation to almost zero. If water consumption is reduced, production costs are lowered. Also, conditions may be less favorable for the onset of diseases including fungus. Irrigation scheduling can be managed precisely to meet crop demands, holding the promise of increased yield and quality.

Agricultural chemicals can be applied more efficiently and precisely with drip irrigation. Since only the crop root zone is irrigated, nitrogen that is already in the soil is less subject to leaching losses. In the case of insecticides, fewer products might be needed. Fertiliser costs and nitrate losses can be reduced. Nutrient applications can be better timed to meet plants' needs.

The drip system technology is adaptable to terrains where other systems cannot work well due to climatic or soil conditions. Drip irrigation technology can be adapted to lands with different topographies and crops growing in a wide range of soil characteristics (including salty soils). It has been particularly efficient in sandy areas with permanent crops such as citric, olives, apples and vegetables.

A drip irrigation system can be automated to reduce the requirement for labour.

Disadvantages

The initial cost of drip irrigation systems can be higher than other systems. Final costs will depend on terrain characteristics, soil structure, crops and water source. Higher costs are generally associated with the costs of pumps, pipes, tubes, emitters and installation. Unexpected rainfall can affect drip systems either by flooding emitters, moving pipes, or affecting the flow of soil salt-content. Drip systems are also exposed to damage by rodents or other animals. It can be difficult to combine drip irrigation with mechanised production as tractors and other farm machinery can damage pipes, tubes or emitters.

Knowledge and Monitoring Requirements

Investment will also be required to build workers capacities in order to accurately manage maintenance and water flow control. For example, drip tape or tubing must be carefully maintained in order to avoid leaking or plugging and emitters must be regularly cleaned to avoid blockage from chemical deposits. In certain cases, it would be necessary to redesign the farm weed control programme.

Costs and Financial Requirements

The technology is widely variable, however the cost of a drip irrigation system ranges from US\$ 800 to US\$ 2,500 per hectare depending on the specific type of technology, automatic devices, and materials used as well as the amount of labor required. Financing for equipment may be available from financial institutions via leasing operations or direct credit. Farmers usually cover installation, design and training costs that represent about 30 to 40 per cent of final costs depending on the size of the land, characteristics and shape, crops, and particular technology applied.

Barriers to Implementation

As with the sprinkler irrigation system, drip technology faces some possible barriers to implementation including lack of access to finance for the purchase of equipment, a higher amount of initial investment involved than other systems, and limited market for repurchased equipment. Even though several suppliers with wide experience may exist, these firms are usually focused on large land extension projects and do not cater for small and medium-sized farmer markets. Technical conditions such as soil clay presence,

irregular rainfall or steep slopes can increase implementation and maintenance costs or affect drip system efficiency. Also, the yield of existing crops irrigated by gravity or another open system can be affected by changing to drip system.

Opportunities for Implementation

Drip irrigation is particularly suitable for use with ground water from wells. It requires institutional arrangements and capacity building of water users to avoid an overuse of aquifer resources and potential conflicts. Drip irrigation technologies can be implemented via a water user association to improve economic benefits and reduce initial investment costs. Drip irrigation is a versatile technology suitable for application in a wide range of contexts. It can be implemented at small or large scales and with low-cost or more sophisticated components. This technology can be employed in conjunction with other adaptation measures such as the establishment of water user boards, multi-cropping and fertiliser management. Promoting drip irrigation contributes to efficient water use, reduces requirements for fertilisers and increases soil productivity. It is particularly suitable in areas with permanent or seasonal water scarcity, since crop varieties to plant can also be adaptable to these conditions.

A Real Example of Application

Box 4.13 Drip Irrigation for Olives in the Desert of Acari Valley, Peru

Olives trees are particularly affected by climate change. To maximise yields and quality, these trees need moderate to high temperatures during the summer and moderate to cool temperatures in the winter. Also, the trees need to be irrigated by late winter in order for the flowers to develop. A key characteristic of olive trees (a feature of many fruits trees) is biennial bearing. This means that a good harvest year ('on year') follows another with far fewer olives on the trees ('off year'). Harvest results affect two years in a row. This makes olives trees particularly sensitive to climate change effects because higher or lower temperatures can affect yield for two or more years. Farmers in the Acari Valley mainly use a gravity system to irrigate. They flood trees for long hours during summer time when water is available and with smaller quantities when water is in short supply in the winter. This regime affects tree rooting systems (by reducing the oxygen available) and soil conditions (by flushing out nutrients, particularly nitrogen), promoting fungus development and consequently increasing costs and reducing yields and olive quality. From 2006, a drip irrigation system model began to be adopted by several small-scale farmers. Financing was obtained in certain cases from a government programme (the Sectorial Irrigation Programme). The Programme offered technical assistance and workshops to promote the use of the drip system in the valley. In addition, it supported system implementation costs by providing co-financing for equipment costs (up to US\$500 per hectare). In other cases, farmers (after learning about the advantages of system) negotiated and got direct credit from suppliers. With the drip irrigation system in place, farmers can now use reservoirs and tanks to provide a stable, year-long water supply to their lands, especially during late winter when nutrients and soil moisture are more vital for flowering. After four years, results are very positive. Yields have increased by 28-35 per cent year by year. More significantly, water consumption has been reduced by 42 per cent. Alternate off-year production has been increased by up to 60 per cent of full on-year production (it used to be around 20 per cent). Adopting a more efficient irrigation system has also strengthened relationships between farmers in Water User Associations.

Source: Farm Manager Agriver SAC, 2011

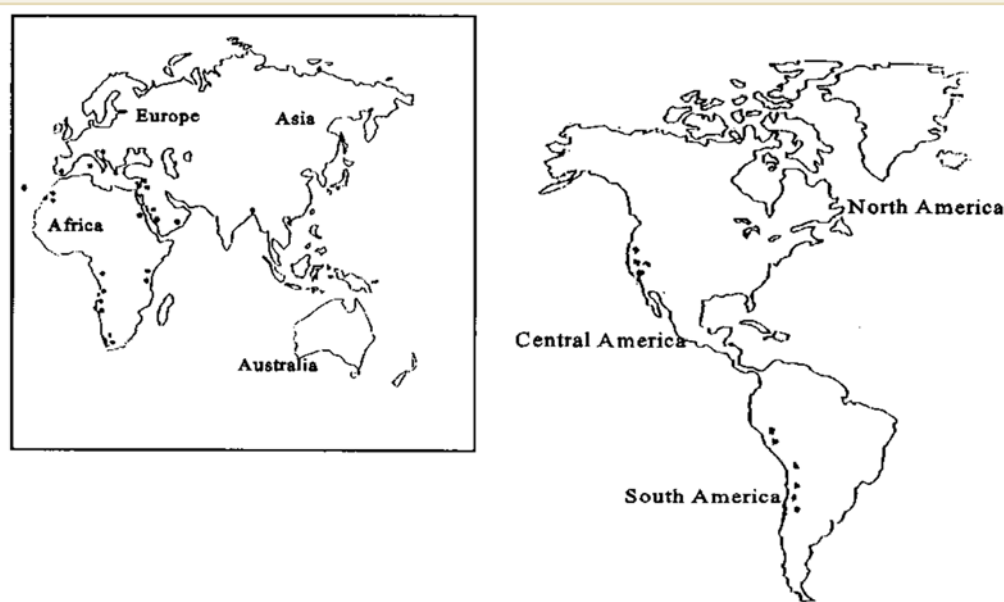
4.2.2 Fog Harvesting

Definition

Fogs have the potential to provide an alternative source of fresh water in dry regions and can be harvested through the use of simple and low-cost collection systems. Captured water can then be used for agricultural irrigation and domestic use. Research suggests that fog collectors work best in locations with frequent fog periods, such as coastal areas where water can be harvested as fog moves inland driven by the wind. However, the technology could also potentially supply water in mountainous areas if the water is present in stratocumulus clouds, at altitudes of approximately 400 m to 1,200 m (UNEP, 1997). According to the International Development Research Centre (1995), in addition to Chile, Peru, and Ecuador, the areas with the most potential to benefit include the Atlantic coast of southern Africa (Angola, Namibia), South Africa, Cape Verde, China, Eastern Yemen, Oman, Mexico, Kenya, and Sri Lanka.

Box 4.14 Potential Application of Fog Harvesting Technology

“Fog harvesting has been implemented successfully in the mountainous coastal areas of Chile, Ecuador, Mexico, and Peru. Because of similar climatic and mountainous conditions, this technology also could be implemented in other regions as shown in the figure below.”



Source: UNEP, 1997

Description

Fog harvesting technology consists of a single or double layer mesh net supported by two posts rising from the ground. Mesh panels can vary in size. The ones used by the University of South Africa in a fog harvesting research project measured 70 m² (UNISA, 2008) whereas in the Yemen, a set of 26 small Standard Fog Collectors (SFC) of one m² were constructed (Schemenaur et al, 2004). The material used for the mesh is usually nylon, polyethylene or polypropylene netting (also known as ‘shade cloth’) which can be produced to various densities capable of capturing different quantities of water from the fog that

passes through it (UNEP, 1997). The collectors are positioned on ridgelines perpendicular to prevailing wind and capture and collect water when fog sweeps through. The number and size of meshes chosen will depend on the local topography, demand for water, and availability of financial resources and materials. According to FogQuest the optimal allocation is single mesh units with spacing between them of at least 5 m with additional fog collectors placed upstream at a distance of at least ten times higher than the other fog collector. In South Africa, the University research project arranged several mesh panels together in order to expand the water catchment area and provide greater stability to the structure in windy conditions (UNISA, 2008).

The collector and conveyance system functions due to gravity. Water droplets that collect on the mesh run downwards and drip into a gutter at the bottom of the net from where they are channelled via pipes to a storage tank or cistern. Typical water production rates from a fog collector range from 200 to 1,000 litres per day, with variability occurring on a daily and seasonal basis (FogQuest). Efficiency of collection improves with larger fog droplets, higher wind speeds, and narrower collection fibres/mesh width. In addition, the mesh should have good drainage characteristics. Water collection rates from fog collectors are shown in Table 4.9 below.

Table 4.9 Water Collection Rates from Fog Collectors

Project	Total Collecting Surface (m ²)	Water Collected (litres/day)
University of South Africa	70	3,800
Yemen	40	4,500
Cape Verde	200	4,000
Dominican Republic	40	4,000
Eritrea	1,600	12,000

Sources: UNISA, 2008; Schemenauer et al, 2004; Washtechology, 2011; FogQuest

The dimensions of the conveyance system and storage device will depend on the scale of the scheme. Storage facilities should be provided for at least 50 per cent of the expected maximum daily volume of water consumed. For agricultural purposes, water is collected in a regulating tank, transferred to a reservoir and then finally into an irrigation system that farmers can use to water their crops (UNEP, 1997).

Operation and maintenance are relatively simple processes once the system has been properly installed. Nevertheless, an important factor in the sustainability of this technology is the establishment of a routine quality control programme which should include the following tasks (UNEP, 1997):

- Inspection of mesh nets and cable tensions to prevent loss in water harvesting efficiency and avoid structural damage
- Maintenance of nets, drains and pipelines to include removal of dust, debris and algae
- Maintenance of the storage tank or cistern to prevent accumulation of fungi and bacteria

- Where spare parts are not available locally, it is recommended that a stock of mesh and other components be kept in reserve as local supply might be restricted, especially in remote mountainous regions.

The Technology and its Contribution to Adaptation

Drought caused by climate change is leading to reductions in the availability of fresh water supplies in some regions. This is having an impact on agricultural production by limiting opportunities for planting and irrigation. Fog harvesting provides a way of capturing vital water supplies to support farming in these areas. Furthermore, when used for irrigation to increase forested areas or vegetation coverage, water supplies from fog harvesting can help to counteract the desertification process. If the higher hills in the area are planted with trees, they too will collect fog water and contribute to the aquifers. The forests can then sustain themselves and contribute water to the ecosystem helping to build resilience against drier conditions.

Advantages

Atmospheric water is generally clean, does not contain harmful micro-organisms and is immediately suitable for irrigation purposes. In a number of cases, water collected with fog harvesting technology has been shown to meet World Health Organisation standards (UNISA, 2008; WaterAid, no date). The environmental impact of installing and maintaining the technology is minimal (WaterAid, no date). Once the component parts and technical supervision have been secured, construction of fog harvesting technology is relatively straightforward and can be undertaken on site. The construction process is not labour intensive, only basic skills are required and, once installed, the system does not require any energy for operation. Given that fog harvesting is particularly suitable for mountainous areas where communities often live in remote condition, capital investment and other costs are generally found to be low in comparison with conventional sources of water supply (UNEP, 1997).

Disadvantages

Fog harvesting technologies depend on a water source that is not always reliable, because the occurrence of fogs is uncertain. However, certain areas do have a propensity for fog development, particularly, mountainous coastal areas on the western continental margin of South America. Further, calculation of even an approximate quantity of water that can be obtained at a particular location is difficult (Schemenauer and Cereceda, 1994). This technology might represent an investment risk unless a pilot project is first carried out to quantify the potential water rate yield that can be anticipated in the area under consideration.

Knowledge and Monitoring Requirements

A range of meteorological and geographic information is required for choosing a site to implement fog harvesting technology, including predominant wind direction and the potential for extracting water from fogs (such as frequency of fog occurrence and fog water content). A feasibility study and pilot-scale assessment should also be carried out to assess the magnitude and reliability of the fog water source. Some of this information can usually be gathered from government meteorological agencies but may require local meteorological stations and the use of a neblinometer¹³ for collection of localised data (Box 4.15).

Box 4.15 Key Information Requirements for Assessing Fog Harvesting Suitability

Global wind patterns: persistent winds from one direction are ideal for fog collection. The high-pressure area in the eastern part of the South Pacific Ocean produces onshore, south-west winds in northern Chile for most of the year and southerly winds along the coast of Peru.

Topography: it is necessary to have sufficient topographic relief to intercept the fogs/clouds. Examples on a continental scale, include the coastal mountains of Chile, Peru, and Ecuador, and, on a local scale, include isolated hills or coastal dunes.

Relief in the surrounding areas: it is important that there are no major obstacle to the wind within a few kilometres upwind of the site. In arid coastal regions, the presence of an inland depression or basin that heats up during the day can be advantageous, as the localised low pressure area thus created can enhance the sea breeze and increase the wind speed at which marine cloud decks flow over the collection devices.

Altitude: the thickness of the stratocumulus clouds and the height of their bases will vary with location. A desirable working altitude is at two-thirds of the cloud thickness above the base. This portion of the cloud will normally have the highest liquid water content. In Chile and Peru, the working altitudes range from 400 m to 1,000 m above sea level.

Orientation of the topographic features: it is important that the longitudinal axis of the mountain range, hills, or dune system be approximately perpendicular to the direction of the wind bringing the clouds from the ocean. The clouds will flow over the ridge lines and through passes, with the fog often dissipating on the downwind side.

Distance from the coastline: there are many high-elevation continental locations with frequent fog cover resulting from either the transport of upwind clouds or the formation of orographic clouds. In these cases, the distance to the coastline is irrelevant. However, areas of high relief near the coastline are generally preferred sites for fog harvesting.

Space for collectors: ridge lines and the upwind edges of flat-topped mountains are good fog harvesting sites. When long fog water collectors are used, they should be placed at intervals of about 4.0 m to allow the wind to blow around the collectors.

Crestline and upwind locations: slightly lower-altitude upwind locations are acceptable, as are constant-altitude locations on a flat terrain. But locations behind a ridge or hill, especially where the wind is blowing downslope, should be avoided.

Source: UNEP, 1997

Aside from hard data detailed in Box 4.15, expertise in the construction and maintenance of the fog harvesting technology is required and training should be provided to local communities to undertake regular quality control and equipment inspections.

Costs and Financial Arrangements

The costs vary depending on the size of the fog catchers, quality of and access to the materials, labour, and location of the site. Small fog collectors cost between \$ 75 and \$ 200 each to build. Large 40-m² fog collectors cost between \$1,000 and \$1,500 and can last for up to ten years. A village project producing about 2,000 litres of water per day will cost about \$ 15,000 (FogQuest, 2011). Multiple-unit systems have the advantage of a lower cost per unit of water produced, and the number of panels in use can be changed as climatic conditions and demand for water vary (UNEP, 1997). Community participation will help to reduce the labour cost of building the fog harvesting system.

Institutional and Organisational Requirements

It is generally recommended that the local population is involved in the construction of the project (UNEP, 1997; WaterAid, no date). Community participation helps to remove labour costs and also helps to ensure a sense of ownership by the community and a commitment to maintenance. A community management committee could be set up and consist of trained individuals responsible for repair and maintenance tasks, helping to ensure the long-term sustainability of the technology. In the initial stages, government subsidies may be required to buy raw materials and fund technical expertise.

Barriers to Implementation

Several challenges and issues have emerged from fog harvesting projects implemented to date:

- Where fog is a seasonal source, water has to be stored in large quantities for dry season use (WaterAid, no date)
- If not properly maintained, water quality becomes an issue during low-flow periods
- Fog water collection requires specific environmental and topographical conditions, limiting its application to specific regions
- Procurement and transportation of materials is hindered by remote locations and steep terrain
- Strong winds and snow fall can result in structural failure during the winter season
- Water yield is difficult to predict, requiring feasibility studies prior to large scale implementation
- For harvesting to be effective, frequent fogs are needed and sufficient water collected for the investment to be cost-effective. This limits the technologies to areas with specific conditions
- There are few commercial producers of mesh currently in operation, with main suppliers located in the Chile. There is none in Africa, North America or Asia (FogQuest, 2011). Therefore implementation and maintenance can be costly[due to import or transportation].

Opportunities for Implementation

Fog water collection has emerged as an innovative technology for mountainous communities without access to traditional sources of water. Still largely in a state of development, there is opportunity for research and development into fog harvesting technology and its potential to support agricultural production. Given the lack of mesh suppliers, using locally available materials for component parts presents an opportunity for local business development. This technology also provides an opportunity to restore natural vegetation and support agricultural practices through the sourcing of clear water for crops and livestock.

A Real Example of Application

Box 4.16 Development of Fog Water Collection in Nepal

Between 1997 and 2004, four fog harvesting pilot projects were implemented in Eastern Nepal, in Dhankutta, Ilam and Taplejung. These projects proved to be effective in addressing a need for water in remote regions. However, there were several challenges and problems associated with the implementation of fog water schemes. These included engineering integrity, water quality, water storage and maintenance, and perception by villagers. All of these technical and social setbacks raise concerns over fog water collection technologies' long-term viability and sustainability in Nepal. Nonetheless, fog harvesting, if nurtured and further developed, may be able to reduce the struggle to procure water very effectively in many hill areas.

Some emerging issues include:

- **Climate:** in Nepal, fog harvesting does not coincide with the dry season when shortages are experienced
- **Site selection:** site selection can be guided by general climatological and topological parameters. On a macro, or regional scale, educated statements can be made about the suitability of this technology. On a micro scale however, identifying communities and meaningfully assessing the environmental conditions is a difficult task
- **Technical:** though simple in its theory and design, construction of fog harvesting technology in Nepal proved to be very challenging. The terrain, the procurement and movement of materials, and harsh weather made installation an expensive and time-consuming commitment
- **Water storage facilities:** to hold all the water collected, there must be a reservoir tank with enough capacity to meet the minimum requirements of the community through the dry months
- **Water quality:** community perceptions of the water source have been affected by issues of turbidity. During periods of no fog, dust and dirt accumulates on the nets and is washed into the water supply, resulting in turbid water and bacterial contamination. Bird droppings and insects are another concern
- **Maintenance – problems included:** ensuring the existence of a maintenance fund (money not collected or used), community conflicts due to lack of cooperation, spare parts not available on local markets, technology not user-friendly, lack of monitoring and evaluation schedule
- **Social perceptions:** unfavourable perception of fog water, villagers against the idea of their community being a 'test site' for the technology when water issues are so important, lack of coordinated community participation
- **Institutional:** strong organisation of information, materials and data is required. Technical know-how should be transferred to local community members (or local NGOs). Effort should be made to document and share information on the experiences.

Source: Apigian, 2005

4.2.3 Rainwater Harvesting

Definition

Rainfall can provide some of the cleanest naturally occurring water that is available. There is considerable scope for the collection of rainwater when it falls, before huge losses occur due to evaporation, transpiration,

and runoff and drainage – before it becomes contaminated by natural means or man-made activities. Rainwater harvesting is a particularly suitable technology for areas where there is no surface water, or where groundwater is deep or inaccessible due to hard ground conditions, or where it is too salty or acidic.

Description

Rainwater harvesting is defined as a method for inducing, collecting, storing and conserving local surface runoff¹⁴ for agriculture in arid and semi-arid regions (Boers and Ben-Asher, 1982). Both small and large-scale structures are used for rainwater harvesting collection and storage including water pans, tanks, reservoirs and dams. Commonly used rainwater harvesting systems are constructed from three principal components:

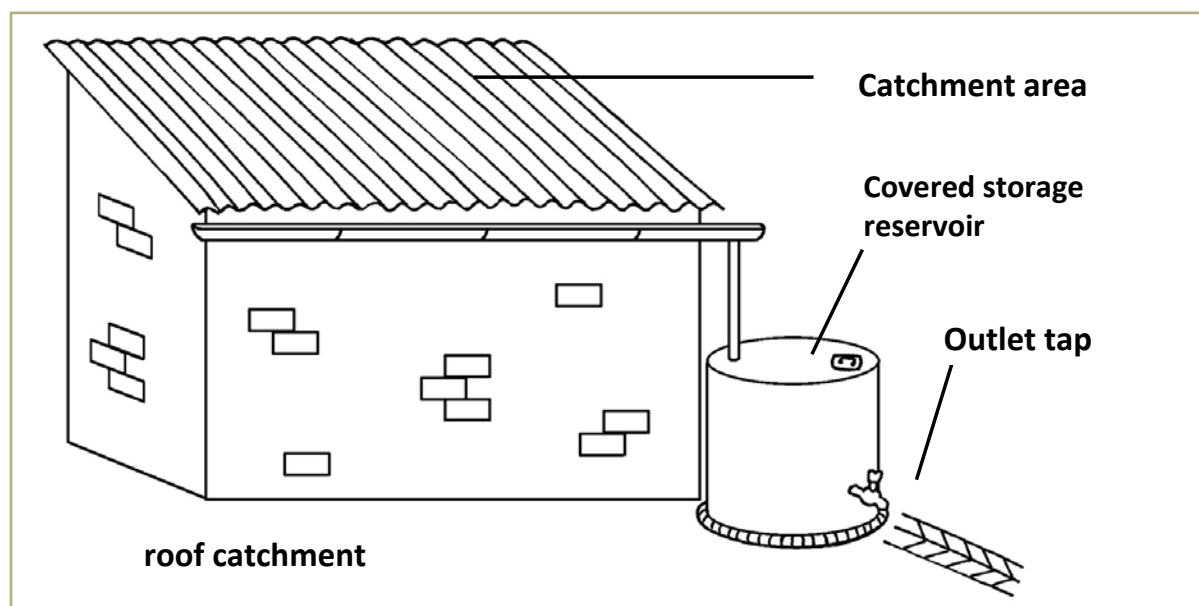
Catchment Area

The catchment area is the area where the rainfall or water runoff is initially captured and is in most cases either the roof-top of a house or building, ground surface or rock surface.

Roof-top

In the roof-top method (Figure 4.5) water from rainfall is collected in vessels at the edge of the roof or channelled to a storage system via gutters and pipes. Roofs can be constructed with a range of materials including galvanised corrugated iron, aluminium cement sheets, and tiles and slates. Thatch or palm leafed roofs can provide a low-cost alternative but can be difficult to clean and can taint the runoff. Tiled roofs, or roofs sheeted with corrugated mild steel or other materials are preferable, since they are the easiest to construct and give the cleanest water (WaterAid, no date). Health hazards can arise from roofs with asbestos sheeting, metallic paint or other coverings that can contaminate the water (Gould, 1992). Roof-top collection is suitable for household level application and can provide freshwater for domestic purposes and small-scale farming.

Figure 4.5 Schematic of a Typical Rainwater Catchment System

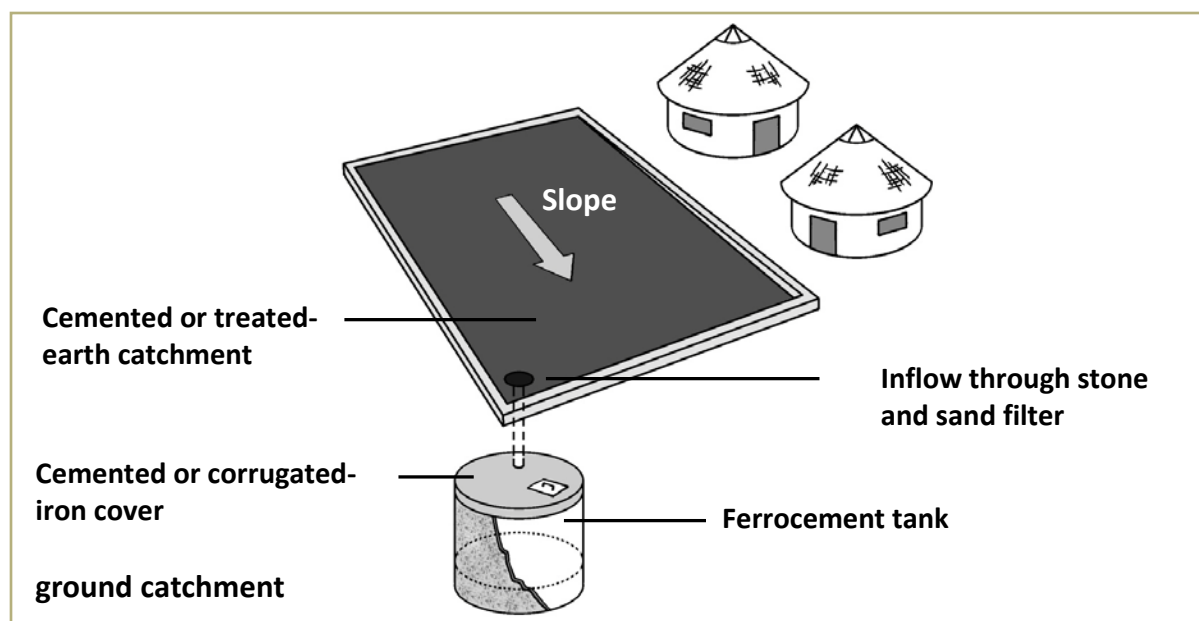


Source: UNEP IETC, 1998

Ground-surface

In the ground surface method water flowing along the ground during the rains is usually diverted toward a tank below the surface (Figure 4.6). There is greater possibility of water loss than the roof-top system due to infiltration into the ground. The water is generally of lower quality than that collected directly from rainfall. Techniques available for increasing runoff within ground catchment areas include: i) clearing or altering vegetation cover, ii) increasing the land slope with artificial ground cover, and iii) reducing soil permeability by the soil compaction and application of chemicals (UNEP, 1982). Impermeable membranes can also be used to facilitate run-off. Ground catchment is applicable for low topographic areas and is suitable for large-scale agricultural production as it allows for in-situ storage and usage of fresh water for irrigation.

Figure 4.6 Ground Catchment System



Source: UNEP IETC, 1998

Box 4.17 Ground Surface Collection in Paraguay

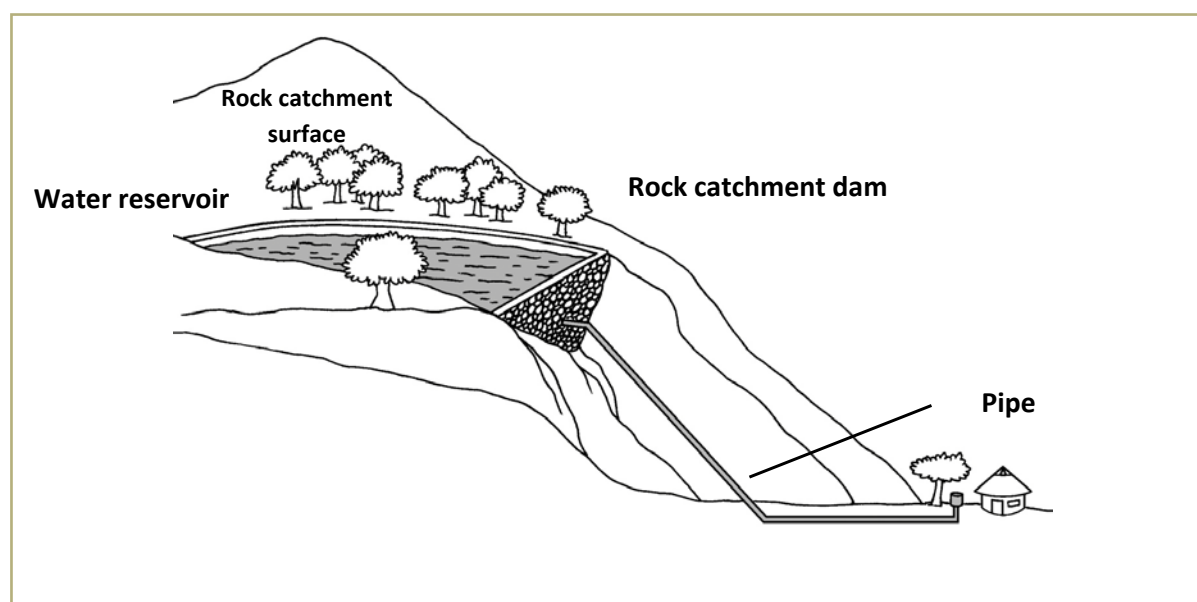
In Paraguay, areas of low topography used for rainwater storage are known as *tajamares*. *Tajamares* are constructed in areas with clay soils at least 3 m deep. The *tajamares* are served by distribution canals that convey water from the storage area to the areas of use. The collection and storage areas need to be fenced to avoid contamination by animals. This technology is usually combined with storage tanks built of clay. The water is delivered from the in situ rainfall collection area to the storage tank by means of a pump, usually driven by a windmill. Water stored in *tajamares* is normally used for livestock watering and may be used for domestic consumption after filtration and/or chlorination. Individual *tajamares* have also been used as a means of artificially recharging groundwater aquifers. The construction cost of a *tajamar* in Paraguay has been reported at \$4,500. This cost includes not only the cost of soil preparation, but also the cost of ancillary equipment such as the storage tank and windmills.

Source: UNEP, 1997

Rock Surface

Rock surfaces can also be used as collection catchments. Bedrock surfaces found within rocky top slopes or exposed rock outcrops in lowlands often have natural hollows or valleys which can be turned into water reservoirs by building a dam (Figure 4.7). Developing a rock catchment area typically involves clearing and cleaning the site from vegetation and marking out the catchment area to be enclosed with gutters. Rock surfaces should not be fractured or cracked, as this may cause the water to leak away to deeper zones or underneath the dam. As with ground catchments, water is generally of lower quality than direct rainfall collection. Water quality can be improved if access to the area (for example, by animals and children) is limited (WaterAid, no date).

Figure 4.7 Rock Catchment



Source: UNEP IETC, 1998

Conveyance System

Several types of conveyance systems exist for transporting water from the catchment to the storage device, including gutters, pipes, glides, and surface drains or channels. Larger-scale conveyance systems may require pumps to transfer water over larger distances. These should be constructed from chemically inert materials such as wood, bamboo, plastic, stainless steel, aluminium, or fibreglass, in order to avoid negatively affecting on water quality (UNEP, 1997). In the case of rock catchments, gutters can be constructed from a stone wall built with rough stones/hardcore and joined with mortar (UNEP IETC, 1998). For household-level rainwater harvesting, gutters, down pipes, funnels and filters are required to transfer and clean collected water before it enters the storage device.

Storage Device

Storage devices are used to store the water that is collected from the catchment areas and are classified as (i) above-ground storage tanks and (ii) cisterns or underground storage vessels. These facilities can vary in size from one cubic metre to up to hundreds of cubic metres for large projects. Common vessels

used for small-scale water storage are plastic bowls, buckets, jerry cans, clay or ceramic jars, cement jars, and old oil drums. Devices can be made cheaply with locally available materials such as bamboo and steel and coated with a sand and cement mix (WaterAid, no date). Increasingly popular are ferro-cement tanks in which mortar is applied to a cylindrical wire frame which helps to control cracking. These tanks are feasible up to a size of 100 m³. For storing larger quantities of water the system will usually require a bigger tank or cistern with sufficient strength and durability. Typically these tanks can be constructed out of bricks coated with cement. For water captured from a rock catchment, a dam is the more common form of storage device.

Maintenance is required for the cleaning of the tank and inspection of the gutters, pipes and taps and typically consists of the removal of dirt, leaves and other accumulated materials. Such cleaning should take place annually before the start of the major rainfall season with regular inspections. In regions with unpredictable rainfall, more regular maintenance and cleaning will be required to ensure that the equipment is maintained in good working order. Cracks in the storage tanks can create major problems and should be repaired immediately to avoid water loss. In the case of ground and rock catchments, additional care is required to avoid damage and contamination by people and animals and to keep the catchment area free from vegetation.

How the Technology Contributes to Climate Change Adaptation

Climate change is disrupting global rainfall patterns meaning some parts of the world are suffering from a drastic drop in precipitation leading to a fall in water levels in many reservoirs and rivers. In Sub-Saharan Africa where two-thirds of the region is desert and dryland, the need for improving water management in the agriculture sector is particularly critical. Rainwater harvesting represents an adaptation strategy for people living with high rainfall variability, both for domestic supply and to enhance crop, livestock and other forms of agriculture (UNEP and SEI, 2009).

Generally, the amount of water made available through rainwater harvesting is limited and should be used prudently to alleviate water stress during critical stages of crop growth. Supplemental irrigation is a key strategy and can help increase yields by more than 100 per cent. A small investment providing between 50 and 200 mm of extra water per hectare per season for supplemental irrigation, in combination with improved agronomic management, can more than double water productivity and yields in small-scale rain-fed agriculture (UNEP and SEI, 2009).

Advantages

Rainwater harvesting technologies are simple to install and operate. Local people can be easily trained to implement such technologies, and construction materials are usually readily available. Rainwater harvesting is convenient because it provides water at the point of use and farmers have full control of their own systems. Use of rainwater harvesting technology promotes self-sufficiency and has minimal environmental impact. Running costs are reasonably low. Construction, operation and maintenance are not labour-intensive. Water collected is of acceptable quality for agricultural purposes. Other benefits include increasing soil moisture levels and increasing the groundwater table via artificial recharge. Rainwater harvesting and its application to achieving higher crop yields can encourage farmers to diversify their enterprises, such as increasing production, upgrading their choice of crop, purchasing larger livestock animals or investing in crop improvement inputs such as irrigation infrastructure, fertilisers and pest management (UNEP and SEI, 2009).

Disadvantages

The main disadvantage of rainwater harvesting technology is the limited supply and uncertainty of rainfall. Rainwater is not a reliable water source in dry periods or in time of prolonged drought. Low storage capacity will limit rainwater harvesting potential, whereas increasing storage capacity will add to construction and operating costs making the technology less economically viable. The effectiveness of storage can be limited by the evaporation that occurs between rains. In water basins with limited surplus supplies, rainwater harvesting in the upstream areas may have a damaging impact downstream and can cause serious community conflict. Also, when runoff is generated from a large area and concentrated in small storage structures, there is a potential danger of water quality degradation, through introduction of agro-chemicals and other impurities (UNEP and SEI, 2009).

Knowledge and Monitoring Requirements

Key information for rainwater harvesting planning relates to the supply and demand of water (Box 4.18).

Box 4.18 Knowledge Requirements for the Selection of Rainwater Harvesting Technology

- Rainfall quantity (mm/year)
- Rainfall pattern – the type of rainfall pattern, as well as the total rainfall, which prevails will often determine the feasibility of a rainwater harvesting technology. A climate where rain falls regularly throughout the year will mean that the storage requirement is low and hence the system cost will be correspondingly low and vice versa
- Collection surface area (m²)
- Available storage capacity (m³)
- Daily consumption rate (litres/capita /day)
- Number of users
- Cost – a major factor in any scheme.
- Alternative water sources – where alternative water sources are available, this can make a significant difference to the usage pattern. If there is a groundwater source within walking distance of the dwelling (say within a kilometre or so), then a rainwater harvesting system that can provide a reliable supply of water at the homestead for the majority of the year, will have a significant impact to lifestyle of the user
- Water management strategy – whatever the conditions, a careful water management strategy is always a prudent measure. In situations where there is a strong reliance on stored rainwater, there is a need to control or manage the amount of water being used so that it does not dry up before expected.

Source: Practical Action, no date

Costs and Financial Arrangements

The cost of rainwater harvesting systems will depend on the type of catchment, conveyance and storage tank materials used but in general the costs of rainwater harvesting systems is considered to be low (UNEP, 1997). The provision of the storage tank is the most costly element, and usually represents about 90 per cent of the total cost (WaterAid, no date). A review of 311 case studies on watershed programmes

in India, with rainwater harvesting and rainwater management as important components, found that the mean cost-benefit ratio of such watershed programmes was relatively high at 1:2.14 (Joshi et al, 2005).

In Bhutan, a three-year rainwater harvesting project aimed at safeguarding farmers from water shortages during dry periods and irregularities in the monsoon rainfall had a total budget of \$850,000. Activities included:

- Small scale irrigation development based on rainwater harvesting technologies
- Strengthening farmers involvement and research and extension services
- Vulnerability assessment
- Land survey
- Rural credit
- Project management
- Identification of areas vulnerable to dry spells and erratic monsoon rainfall
- Arial surveys and evaluation of remote sensing images/photographs to determine areas suitable for water harvesting
- Assessment of available and proven rainwater harvesting technologies for adoption
- Technological adaptation to fit the needs and requirements specific to each vulnerable locations
- Research new designs and package improved technologies (studying and modeling runoff behaviour)
- Establish farmers' capacity to mobilise local resources for technology adoption and actual application
- Demonstration of emerging technologies like supplemental water system, dual purpose system, combined system, modelling
- Training farmers in the maintenance of their investments in RWHTs, and effective utilisation of harvested rainwater
- Economic analysis of rainwater harvesting techniques.

The costs of each activity under the Project are shown in Table 4.10 below:

Table 4.10 Budget Breakdown Rainwater Harvesting in Bhutan

Activities	Year 1 (US\$)	Year 2 (US\$)	Year 3 (US\$)
Small scale irrigation development based on rainwater harvesting technologies	50,000	100,000	200,000
Strengthen farmers involvement and research and extension services	100,000	150,000	50,000
Vulnerability assessment	25,000	-	-
Land survey	25,000	10,000	-
Rural credit	-	-	150,000
Project management	10,000	10,000	15,000
Total Cost	210,000	270,000	415,000

Source: UNFCCC, 2008

In Burundi, a four-year project to install pilot rainwater harvesting units and train local technicians in their use totalled \$100,000, as detailed in Table 4.11.

Table 4.11 Activity Costs for Rainwater Harvesting Pilot Scheme in Burundi

Activities	Cost (US\$)
Train A1 or A0 technicians by some 3-month training courses abroad (in Africa) for specialisation in rainwater harvesting/storage and hill irrigation techniques	100,000
Train A2 technicians locally (two per commune, 12 for Bugesera) in rainwater harvesting/storage and hill irrigation techniques	50,000
Set up at least one pilot installation of rainwater harvesting and hill irrigation in each of the six communes of Bugesera	400,000
Facilitate similar installations in targeted farmers/stockbreeders	250,000
Install one clean water conveyance system by photovoltaic pumping in the area of Bugesera	200,000
Total	1,000,000

Source: UNFCCC, 2008

Institutional and Organisational Requirements

Rainwater harvesting technology is simple to install and operate and does not imply any specific institutional or organisational requirements. However, governments and donors could play a key role in providing subsidies for equipment purchases by making the technology accessible to a larger number of farmers, particularly small-scale farmers, who may have problems raising capital investment funds (UNEP and SEI, 2009).

Barriers to Implementation

The cost of rainwater storage systems is often cited as a potential obstacle to wider dissemination of this technology (Gould, 1992). For poorer households some form of financing mechanism, preferable accompanied by a subsidy, will be the only way of acquiring a rainwater harvesting system. A lack of national policy towards rainwater harvesting could also present an obstacle to widespread implementation, access to funding and technical assistance. Communally-owned systems can suffer from lack of protection, care and maintenance (Hatibu and Mahoo, 1999).

Opportunities for Implementation

Low and variable productivity in rainfed agricultural areas is the major cause of poverty of 70 per cent of the world's poor (UNEP and SEI, 2009). Using rainwater harvesting technology therefore offers a real opportunity to increase productivity in regions with low and irregular rainfall. In those regions, development and use of rainwater harvesting can provide a first entry point for success of development programmes from farm to regional level.

A Real Example of Application

Box 4.19 Rainwater Harvesting Project in the Philippines

In The Philippines, rainwater harvesting was initiated in 1989 with the assistance of the IDRC, Canada. About 500 rainwater storage tanks were constructed in the Capiz Province during this project. The capacities of the tanks varied from 2 to 10 m³, and the tanks were made of wire framed ferrocement. The construction of the tanks involved building a frame of steel reinforcing bars (rebar) and wire mesh on a sturdy reinforced concrete foundation. The tanks were then plastered inside and outside simultaneously, which reduced their susceptibility to corrosion when compared with metal storage tanks.

The Philippine rainwater harvesting system was implemented as a part of the income generating activities in the Capiz Province. Initially, loans were provided to fund the capital cost of the tanks and related agricultural operations. Under this arrangement, the project participant took a loan of \$200, repayable over a three year period, and covering the cost not only of the tank but also for one or more income generating activities such as purchase and rearing of pigs costing around \$25 each. Mature pigs can sell for up to \$90 each, which provided an income generating opportunity that could provide sufficient income to repay the loan. This innovative mechanism for financing rural water supplies helped to avoid the type of subsidies provided by many water resources development projects in the past.

Source: Gould, 1992.

Box 4.20 Rainwater Harvesting Realising the Potential of Rainfed Agriculture in India

India ranks first among the rainfed agricultural countries in terms of both extent (86 M ha) and value of produce. The traditional subsistence farming systems have changed and presently farmers have limited options. Farmers have started cultivating high value crops which require intensive use of inputs. Frequent occurrence of mid-season and terminal droughts of one to three weeks consecutive duration during the main cropping season are the dominant reasons for crop (and investment) failures and low yields. Provision of critical irrigation during this period has the potential to improve the yields by 29 to 114 per cent for different crops. A detailed district and agro-ecoregional level study, comprising 604 districts, showed that on a potential (excluding very arid and wet areas) rainfed cropped area of 25 M ha, a rainfall surplus of 9.97 M ha·m was available for harvesting. A small part of this water (about 18%) was adequate to provide one critical irrigation application of 18.75 M ha during a drought year and 22.75 M ha during a normal year. Water used in supplemental irrigation had the highest marginal productivity and increases in rainfed production above 50% were achievable. More specifically, net benefits improved by about 3-times for rice, 4-times for pulses and 6-times for oilseeds. Droughts appear to have limited impact when farmers are equipped with rainwater harvesting systems. Water harvesting and supplemental irrigation was economically viable at the national level and would have limited impacts downstream during normal years. This decentralised and more equitable intervention targeted resource poor farmers and has the potential to serve as an alternative strategy to the proposed river linking and water transfer projects.

Source: Sharma et al. 2008

4.3 Soil Management

Some major and widespread soil changes are expected as a result of global climate change. Increases in CO₂, sea-level rise, changes in vegetative cover and agricultural practices, increases in temperature and changes in rainfall would impact positively or negatively on the fertility and physical conditions of soils, although the precise nature of these changes are subject to major uncertainties. Despite this uncertainty, a range of soil management technologies can help improve soil quality and resilience against negative effects of climate change (Brinkman and Sombroek, 1996) to maintain agricultural productivity.

4.3.1 Slow-forming Terraces

Definition

A terrace is a levelled surface used in farming to cultivate sloping, hilly or mountainous terrain. They can be used on relatively flat land in cases where soil and climate conditions are conducive to erosion. Terraced fields are effective for growing a wide range of crops such as rice, potatoes, maize, olive trees, and vineyards. Terraces have four main functions (Gonzales de Olarte and Trivelli 1999):

- Improve the natural conditions for agricultural production;
- Decrease the rate of erosion;
- Increase soil moisture; and
- Generate positive environmental benefits.

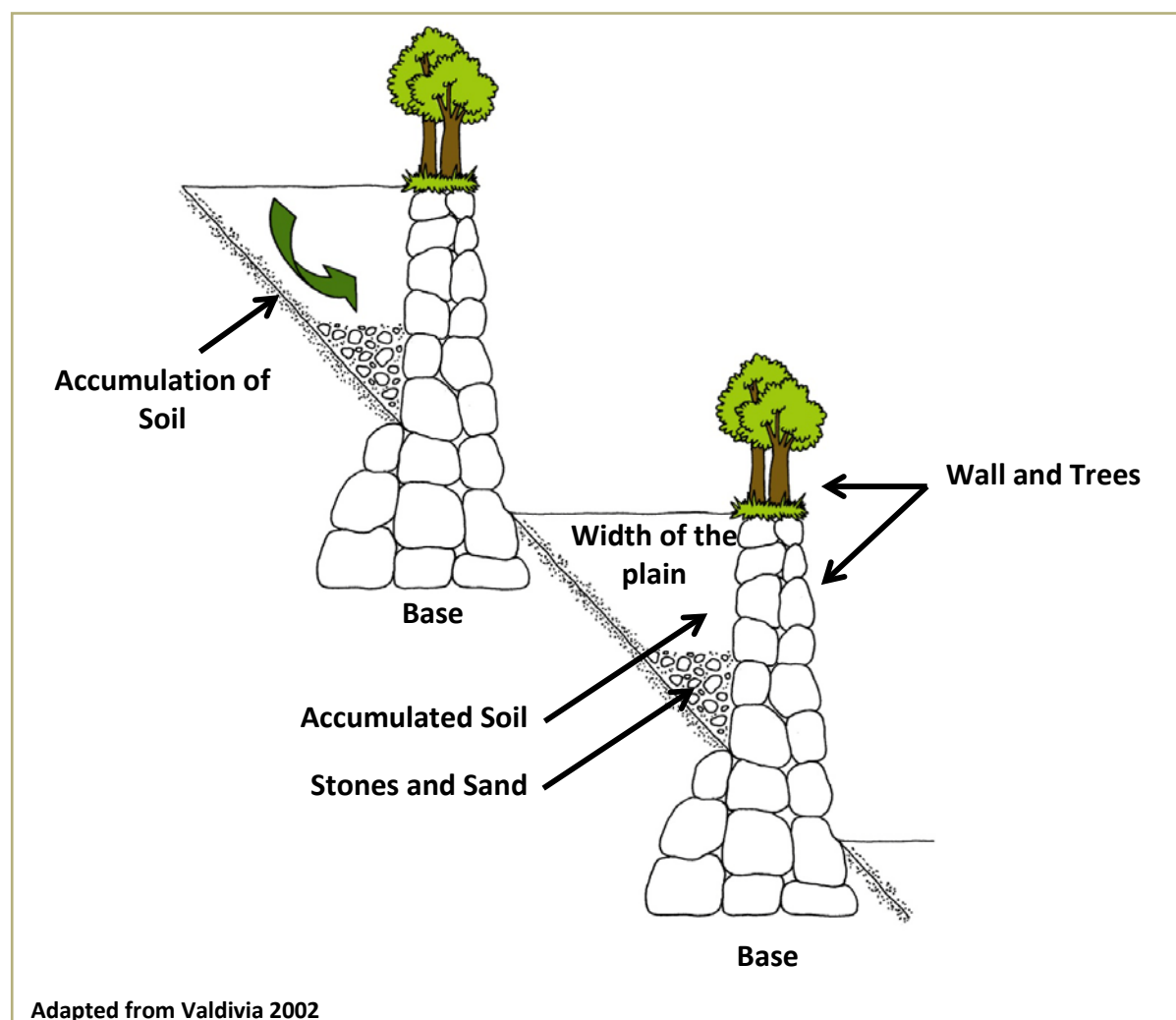
Description

Slow-forming terraces are constructed from a combination of infiltration ditches, hedgerows and earth or stone walls. This technology decreases superficial water run-off, increasing water infiltration and intercepting the soil sediment (UNESCO-ROSTLAC, 1997). Slow-forming terraces are called as such because they take between three and five years, and possibly even ten years, to fully develop.

Slow-forming terraces can be built where the land is marginally to steeply inclined and where the soil is sufficiently deep to create a drag effect. This leads to the formation of steps as sediment accumulates due to rainfall and natural gravity. Level ditches are traced and excavated along the contour line of a slope and then an embankment of earth, stones or plants is constructed at regular intervals. Eroded soil accumulates in these buffer strips every year and terraces slowly form. To avoid intensive rains breaking buffers strips, a one to two per cent inclination is recommended (Fantappiè, no date).

Depending on soil type, ditches should generally be dug 40 cm wide and 40 cm deep. The recommended length of the terrace is between 50 and 80 metres and the height of the slope should be the same as the height of the earth or stone ditches (Soluciones Prácticas-ITDG, 2007).

The best plants to cultivate along the buffer strips should be resistant to local conditions and grow well and fast. Where possible, plants should be used that can provide wood for fuel and feed for livestock. Where possible, leguminous species should be planted to improve nitrogen supply to the soil (Fantappiè, no date). The structure of slow-forming terraces is shown in Figure 4.8.

Figure 4.8 Structure of Slow-forming Terraces

Source: Valdivia, 2002, adapted by Valdivia from Carrion, 1999

Lower investment options have been developed that are also effective in trapping sediment but do not require the building of physical structures. One option is the use of contour planted hedgerows (Young, 1997), this system has been used on 10,000 hectares of land in the Philippines, Rwanda and Haiti. Double hedges of *Leucaena*, *Gliricidia* or similar shrubs are planted 4 to 8 metres apart along the contour. The shrubs are pruned two or three times per year and the leaf and branch material applied to the soil or against the stems of the shrubs, to trap the moving sediment. This leads to the formation of terraces up to 50 cm high in the first two to three years. Another alternative is to use deep rooting grass species such as *Vetiver* or *Panicum* bunch grass often used for cut and carry fodder. An even simpler method is to leave natural vegetative strips to when preparing the soil for planting, which gradually form the stabilised edges of terraces (ICRAF, 1996). These different live-barrier methods of terracing reduce erosion from half to just 2 per cent of the level without the live-barriers, and rainfall infiltration is also significantly improved.

How the Technology Contributes to Climate Change Adaptation

This technology facilitates adaptation to climate change by optimising water use. This is particularly relevant in areas that depend on melting glaciers for their water supply and where there is uncertainty about future rainfall patterns, as occurs in Andean highland areas, for example. Climate variability also affects the soil, since heavy rainfall coupled with poor soil management give rise to landslides and mudslides. In this respect, slow-formation terraces reduce soil erosion and, consequently, the danger of large landslides occurring.

Terraces also provide a method for regulating the micro-climate for agricultural production. By capturing the sun's heat in the rock walls, terraces absorb heat during the daytime and release this nightly helping to create a slightly warmer internal micro-climate which can protect crops from frosts, prolong the growing season and allow for crop diversification (Mars, 2005).

Advantages

Slow-forming terraces allow for the development of larger areas of arable land in rugged terrain and can facilitate modern cropping techniques such as mechanisation, irrigation and transportation on sloping land. They increase the moisture content of the soil by retaining a larger quantity of water. They capture run-off which can be diverted through irrigation channels at a controlled speed to prevent soil erosion. They increase soil exposure to the sun and they replenish the soil and maintain its fertility as the sediments are deposited in each level, increasing the content of organic matter and preserving biodiversity.

Slow-forming terraces have also been shown to increase crop productivity. Research conducted in Peru found that the highest response to the effect of slow formation terraces on productivity was for peas (Table 4.12). Maize, fava beans and potatoes also improved their productivity. The most important reason for this increase is assigned to increased/enhanced water retention.

Table 4.12 Crop Yields (Kg/ha) for the Main Crops in La Encañada, Peru

Crops	Terraced Fields	Non-terraced Fields	Increase (%)
Potato	4300	3800	13.16
Maize	951	794	19.77
Barley	798	726	9.92
Andean Tuber	6709	6331	5.97
Fava bean	755	640	17.97
Pea	830	596	39.26

Source: Valdivia, 2002; CONDESAN, 1995; 60

In Bolivia, slow-forming terraces have been also found to improve crop yield by between 25 and 75 per cent (Table 4.13).

Table 4.13 Crop Yields (t/ha) in the Community of Chullpa K'asa, Bolivia

Crops	Terraced Fields	Non-terraced Fields	Increase (%)
Potato	12	9	33.3
Oca	14	11	27.3
Maize	7	4	75
Wheat	1.3	0.8	63
Barley	1.5	1.2	25

Source: based on Delgadillo and Delgado, 2003

Terraces made using hedgerows or grass strips have the advantage that the material pruned from them can be used as fodder for livestock. Also, the system takes up less space occupying only 10-15 per cent of the land as opposed to 20-30 per cent for ditch and bank terraces, they also require considerably less work to establish.

Disadvantages

In terms of limitations, an economic analysis of terrace investments in the Peruvian Andes has shown that if implemented on a regional-scale, slow-forming terraces can produce varied and sometimes limited returns. Where farmers must pay the full costs of investments, returns can be as low as 10 per cent (Antle et al, 2004). Profitability will depend on additional factors such as interest rates, investment costs and maintenance costs. Cost-benefit analysis should, however, take account of other factors including increased soil productivity and conservation benefits. In addition, slow-formation terraces are formed over a long period of between three and five years, which means that their positive effects are not immediate.

Terraces formed with hedgerows or grasses can compete with associated crops if they are not sufficiently pruned. Generally, this technology is less effective on slopes of more than 30 per cent if hedges are more than 4 m apart.

Knowledge and Monitoring Requirements

Knowledge of terrace design, construction and maintenance, including contouring or levelling techniques as well as knowledge of crops suited to slow-terrace irrigation is required. The most reliable method for defining the contour is the A-frame method¹⁵. To make a judgement on the cost-benefit ratio of a slow-forming terrace scheme, information on capital investments and likely economic returns will be necessary.

Costs and Financial Arrangements

The most costly component of terrace construction is labour which will depend on average local daily wages. The time required to construct a slow-forming terrace will depend on available manpower, the type of soil and the time of year. The basic tools required (such as picks and shovels) usually belong to the farmer and can be used at no extra cost. Once built, annual maintenance costs are minimal (Treacey, 1989). Research indicates that two people can build 7m² of wall in one day. Assuming a common size terrace wall of dimensions 1.8m high and 50m long, two people could restore an entire terrace in two weeks, or build an entirely new one in a slightly longer period of time (Valdivia, 2002). In a project in northern Peru, an initial investment of \$350/ha was required with \$86/ha per annum for maintenance (Yanggen et al, 2003).

Planting of contour hedgerows or grass strips are considerably cheaper to establish, but they require continuous management afterwards.

Institutional and Organisational Requirements

Slow-forming terraces can be implemented at farm-level without specific institutional and organisational arrangements. Notwithstanding, local government agencies can provide assistance in the form of technology transfer and training and subsidies. In terms of social organisation, advantage should be taken of communal work ethics and other mutual cooperation systems for faster construction and more efficient maintenance.

Barriers to Implementation

Barriers to implementation include lack of access to credit by farmers and the slow-rate of return in terms of the time it takes for crop yields to increase, which can take as long as ten years (Yanggen et al, 2003). This can lead to farmers abandoning the technology if long-term benefits are not fully understood. Yanggen et al (2003) estimate that in the Peruvian case, subsidies of around 40 per cent of the total cost of implementing slow-forming terraces would be required to make this technology an attractive alternative to farmers. Given the length of time required for results, lack of access to land or land rights could prevent a farmer from adopting this technology over traditional practices. This is because farmers with precarious forms of land tenancy tend to have shorter planning horizons and view permanent structures requiring long-term investments as riskier (Dvorak, 1996).

The reduction in available land area for cultivation due to the space taken by the ditch and banks, or vegetation strips can be a significant disincentive for farmers with very limited access to land. Also the land cultivated is rented from another land-owner there is little incentive to invest in soil conservation.

Opportunities for Implementation

Terrace construction can provide an opportunity for improvements in soil, crop and water management practices. These in turn can provide opportunities for farmers to increase crop yields and diversify agricultural production to generate additional income.

A Real Example of Application

Box 4.21 Conservation and Reclamation of Deteriorated Volcanic Soils in the Ecuadorian Andes

A project funded by the Italian Ministry for Foreign Affairs and implemented by the NGO MLAL in Guamate, Ecuador conducted research into water conservative practices, including slow-forming terraces.

Key findings

- Native plants such as pasto millin (*festuca arundinacea*) and lupina (*citissus monpesulanus*) were the best plants to use along the terrace walls as wind-breakers because they are very resistant to local conditions (such as soil and climate). They can be used as domestic animal feed, provide wood for fuel and, in the case of lupina (*citissus monpesulanus*), being a leguminous species, also provide a good nitrogen supply to improve overall soil quality.
- The principal crops were potato, quinoa, bean and Andean tubers. The crucial productivity factor was water. For that reason local varieties of potatoes gave ten times better yields than disease resistant selected ones.
- To best preserve soil and water it was necessary to also cover the ground using agronomic techniques such as: mulching, cover crops, and minimal or no tillage.
- Secondly important productivity factors were organic matter and nutrients, especially nitrogen. For that reason better results were also obtained associating potatoes with leguminous species such as beans.

Source: Fantappiè, no date

Box 4.22 Sloping Agricultural Land Technology

This system of planting hedgerows along the contours was developed by the Mindanao Baptist church in the Philippines and was subsequently transferred to other countries such as Nepal.

Essentially the system consists of planting double rows of legume shrubs such as *Gliricidia* or *Leucaena* planted closely spaced within rows (every 20 cm) and 4 to 6 m between rows. The hedgerows are cut back severely every one to two months during the growing season to a height of 1.0 m. Annual crops are grown between the hedgerows, though it is also recommended that every third row be planted to perennial crops to increase overall soil stability. Overall farmers are encouraged to plant a variety of annual and perennial crops and use a variety of shrub species for the hedgerows.

Soil erosion has been found to be reduced to less than 5 per cent of that under none SALT cultivation. A ten year economic study of the system showed that farmer income increased by three-fold after adoption of the SALT production system. Investment in establishing the system is higher than simple maize production during the first two or three years, but generated a net profit by the fifth year. Since its development in the late 1970s the system expanded and was used by at least 5000 farmers by the early 1990s.

Source: <http://www.fao.org/ag/AGP/agpc/doc/PUBLICAT/Gutt-shel/x5556e0y.htm>

Figure 4.9 Planting Hedgegrows along Sloping Agriculture Land in Phillipines

Source: Courtesy of Paolo Lim (2007)

4.3.2 Conservation Tillage

Definition

Tillage is the agricultural preparation of the soil by mechanical, draught-animal or human-powered agitation, such as ploughing, digging, overturning, shovelling, hoeing and raking. Small-scale farming tends to use smaller-scale methods using hand-tools and in some cases draught animals, whereas medium to large-scale farming tends to use the larger-scale methods such as tractors. The overall goal of tillage is to increase crop production while conserving resources (soil and water) and protecting the environment (IBSRAM, 1990).

Conservation tillage refers to a number of strategies and techniques for establishing crops in a previous crop's residues, which are purposely left on the soil surface (see Figure 4.10 and Figure 4.11). Conservation tillage practices typically leave about one-third of crop residue on the soil surface (see Figure 4.12). This slows water movement, which reduces the amount of soil erosion. Conservation tillage is suitable for a range of crops including grains, vegetables, root crops, sugar cane, cassava, fruit and vines.

Conservation tillage is a popular technology in the Americas, with approximately 44 per cent practised in Latin America. Studies suggest there is great potential to bring this technology to Africa, Asia and Eastern Europe, although limiting factors have to be taken into account (see Barriers below) (Derpsch, 2001; GTZ, 1998).

Description

The most common conservation tillage practices are no-till, ridge-till and mulch-till.

No-till is a way of growing crops without disturbing the soil. This practice involves leaving the residue from last year's crop undisturbed and planting directly into the residue on the seedbed. No-till requires

specialised seeding equipment designed to plant seeds into undisturbed crop residues and soil. No-till farming changes weed composition drastically. Faster growing weeds may no longer be a problem in the face of increased competition, but shrubs and trees may begin to grow eventually. Cover crops – ‘green manure’ – can be used in a no-till system to help control weeds. Cover crops are usually leguminous which are typically high in nitrogen can often increase soil fertility.

In ridge-till practices, the soil is left undisturbed from harvest to planting and crops are planted on raised ridges (Figure 4.13). Planting usually involves the removal of the top of the ridge. Planting is completed with sweeps, disk openers, coulters, or row cleaners. Residue is left on the surface between ridges. Weed control is accomplished with cover crops, herbicides and/or cultivation. Ridges are rebuilt during row cultivation.

Figure 4.10 Hoeing in India



Source: Practical Action

Mulch-till techniques involve disturbing the soil between harvesting one crop and planting the next but leaving around a third of the soil covered with residues after seeding. Implements used for mulch-till techniques include chisels, sweeps, and field cultivators.

How the Technology Contributes to Adaptation

Unpredictability of rainfall and an increase in the mean temperature may affect soil moisture levels leading to damages to and failures in crop yields. Conservation tillage practices reduce risk from drought by reducing soil erosion, enhancing moisture retention and minimising soil impaction. In combination, these factors improve resilience to climatic effects of drought and floods (Smith, 2005). Improved soil nutrient recycling may also help combat crop pests and diseases (Holland, 2004).

Figure 4.11 Animal Traction in Nepal

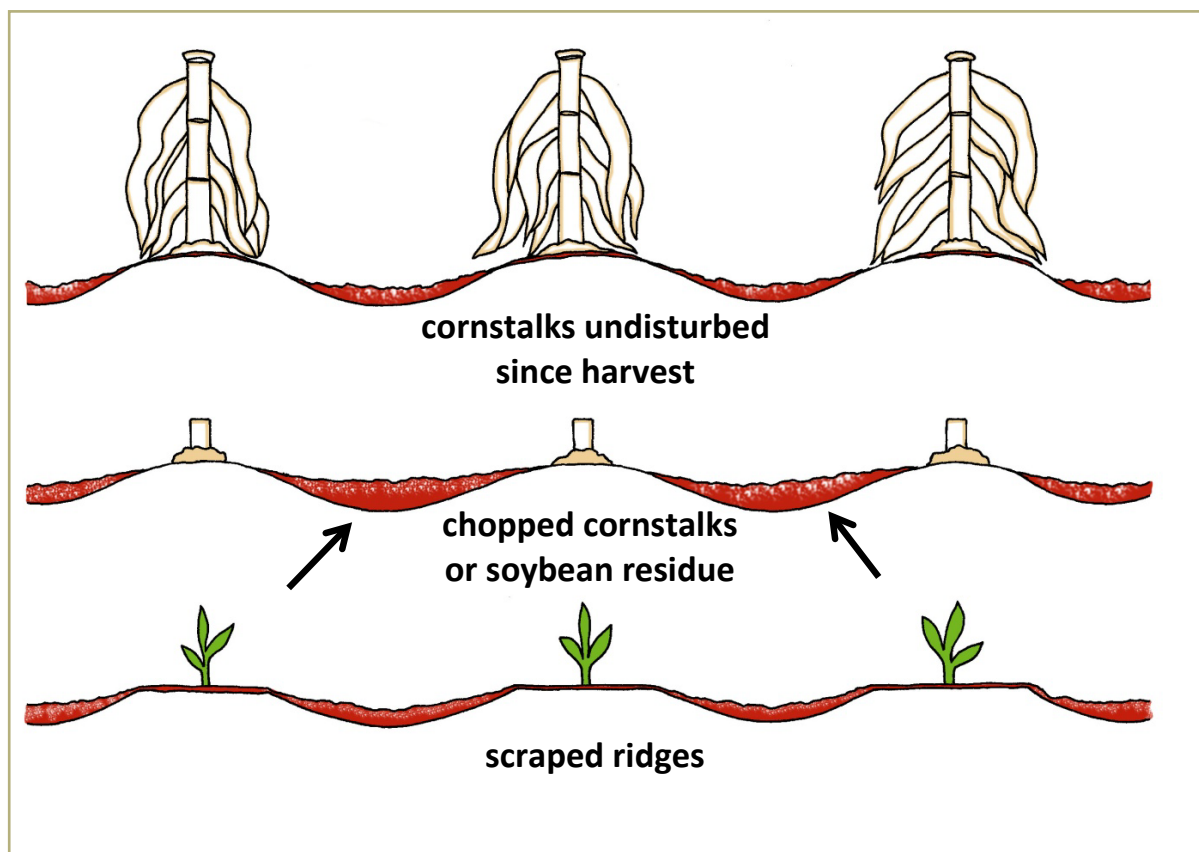


Source: Courtesy of Rajesh, K.C., Practical Action

Figure 4.12 Conservation Tillage Using Discs and Tines



Source: Peeters Agricultural Machinery, Netherlands

Figure 4.13 Ridge Tillage

Source: Adapted from *Introduction to Ridge-tillage for Corn and Soybeans*. Purdue University Cooperative Extension Service ID-180

Advantages

Conservation tillage benefits farming by minimising erosion, increasing soil fertility and improving yield. Ploughing loosens and aerates the soil which can facilitate some deeper penetration of roots. Tillage is believed to help in the growth of microorganisms present in the soil and helps in the mix the residue from the harvest, organic matter and nutrients evenly in the soil. Conservation tillage systems also benefit farmers by reducing fuel consumption and soil compaction. By reducing the number of times the farmer travels over the field, farmers make significant savings in fuel and labour. Labour inputs for land preparation and weeding are also reduced once the system becomes established. In turn, this can increase time available for additional farm work or off-farm activities for livelihood diversification. Also once the system is established, requirement for herbicides and fertilisers can be reduced. According to Sorrenson et al (1998), total economic benefits arising from adoption of the no-tillage technique in small farms of generally less than 20ha in Paraguay have reached around \$941 million.

Disadvantages

Conservation tillage may require the application of herbicides in the case of heavy weed infestation, particularly in the transition phase, until the new balance of weed populations is established (FAO, no date).

The practice of conservation may also lead to soil compaction over time; however this can be prevented with chisel ploughs or subsoilers. Initial investment of time and money along with purchases of equipment and herbicides will be necessary for establishing the system. Higher levels of surface residue may result in higher plant disease and pest infestations, if not managed properly. There is a strong relationship between this technology and appropriate soil characteristics. This is detrimental in high clay content and compact soils.

Knowledge and Monitoring Requirements

Farmers need extensive training to implement conservation tillage. This includes knowledge of crop rotation; analysing soil conditions; monitoring soil temperature and moisture; adjusting nutrient and weed management approaches; and selecting appropriate equipment. Studies in Latin America have shown that the main limitation to the spread of no-tillage technology has been a lack of specific site knowledge about weed control. Information on common weeds, herbicide products (including details of chemical and toxicological characteristics) and application technologies are therefore a key knowledge requirement for application of no-tillage technologies (Derpsch, 2001).

Institutional and Organisational Requirements

Farmers can be supported by national, regional and local farmer's organisations to equipment. In Zambia, the Africare Smallholder Agricultural Mechanisation Promotions (SAMEP) programme has assisted small-scale farmers to access technologies for conservation tillage through working with rural entrepreneurs to broaden the equipment supply base and provide spare parts (Sakala, 1999). This style of programme could be broadened to improve access to other inputs such as cover crop seeds, herbicides and fertilisers. Private and public sector equipment suppliers also have a role in responding to demands from different types of farmers for adapted tools and equipment.

Costs and Financial Requirements

The cost of equipment for conservation will depend on whether the land is tilled with motorised traction, animal-draught or manpower. The most important cost for larger producers will be machinery and fuel. However, higher herbicide applications could offset these savings, especially in the initial adoption stages. On smaller-sized farms, savings in labour costs could be substantial. A study in Nigeria has shown conservation tillage practices to reduce labour inputs by around 50 per cent compared to traditional systems (Ehui et al, 1990). Financial incentives and subsidies may be required to assist farmers to adopt this practice. In Brazil, monetary incentives were found to be highly successful in motivating group formation among farmers, leading to an increase in cooperation and technology uptake (World Bank, 2000).

Barriers to Implementation

A lack of locally-appropriate knowledge and/or poor research and development for conservation tillage technology presents one of the main barriers to uptake (Derpsch, 2001). Likewise, where there is no local production or availability of equipment and other inputs, such as herbicides, then costs will rise significantly and may present a barrier to implementation. Ecological barriers to no-tillage production systems include low precipitation with low biomass production, short growing seasons and soils at risk of water logging. Socio-economic constraining factors include: strong demand for crop residues as forage for livestock, uncertain land use rights, poorly developed infrastructure (market, credit, extension service) (GTZ, 1998).

Opportunities for Implementation

In Latin America, the uptake of this technology was greatly facilitated by exchange of information through farmers associations (World Bank, 2000), provision of publications with adequate, practical information on technology implementation and studies showing positive economic returns (Derpsch, 2001).

A Real Example of Application

Box 4.23 Conservation Tillage in Brazil

In Brazil no-till production has increased from 180,000 hectares in 1992 to 6,000,000 hectares in 2002. Producers have found that no-till techniques within certain planting sequences each year as well as longer-term crop rotations allow producers to increase production by 10 per cent. They also allow producers to reduce use of lime, pesticides, and fungicides by 50 per cent or more, and the use of other chemicals by 10 per cent.

Reduced Costs, Higher Returns

The net return per hectare is almost 50 per cent higher than that of producers using conventional methods. Less machinery is required for no-till planting than for conventional tillage. Even so, for farmers who have already invested large amounts in machinery for conventional cultivation, this could be a burden. In addition, while no-till cultivation requires less machinery, it requires some specialised pieces of equipment that would have to be purchased. However, the new machinery could be phased in over time or custom planters could be hired to plant the crops. In general, there do not appear to be any significant financial barriers to the adoption of no-till technology.

No-till Reduces Soil Erosion

With no-till, soil erosion can be reduced to as little as 5.6 tons of soil per hectare (t/ha) per year. The rainfall runoff on fields under conventional tillage is typically of the order of 138 mm per month. With no-till practices the runoff can be reduced to about 42 mm. The reduced runoff is the result of crop residues on the soil surface slowing the movement of water, allowing more time for the water to be absorbed by the soil and stored for later plant use or released more slowly over time.

Economic Benefits

Estimated annual benefits of adopting no-till agriculture techniques amount to around \$1,386 million on 35 per cent and \$3081 million on 80 per cent of a total cultivated area of 15.4 million hectares.

Barriers to Application

If anything, the main barriers are cultural. Producers are not comfortable with the new technology because it runs counter to how they have farmed in the past. In addition to the financial returns from no-till, there are also a number of conservation gains. In Brazil conventional tillage typically causes soil losses of some 23.6 tons per hectare (t/ha) per year.

Source: Clay, 2004

Box 4.24 Ridge Tillage and Natural Vegetation Strips as Erosion Barriers in the Philippines

A project coordinated by ICRAF in the Philippines worked with farmers to compare the effects of combining different soil conservation techniques during a three-year period. Traditionally farmers plough and harrow twice per year and hand plant seeds of hybrid maize. The ridge tillage was done using the same mouldboard plough and draught animal that the farmers traditionally used. Farmers also traditionally plough on the contour, to the best of their ability, to reduce erosion.

The systems that were compared include ridge tillage and natural vegetation strips either alone or combined. Ridge tillage creates alternate strips of tilled and untilled land with the crop planted in the untilled strip. The inter-row is the tilled strip to control weeds and to hill up the untilled ridge. Using animal power a shallow furrow is planted through the stubble of the previous crop and seeds planted in the same row. Then the mouldboard plough is used to cultivate and bury the weeds in the inter-row to initially bury the weeds and a second time to hill up at about one month after planting. If weed growth is considerable herbicide use may be necessary. Usually the second crop is planted directly in the rows without further tillage, though herbicide use may be necessary.

The natural vegetation strips were laid out approx every 8 m or a vertical drop of 1.5 m, and occupied about 10 per cent of the land area.

Key Findings

- The ridge tillage was found to reduce soil loss by a half to a third of the traditional contour ploughing and maize yields were the same, but with the added advantage that the ridge-tilled system was had lower costs because less cultivation was needed.
- The vegetation strips reduced erosion to less than 10 per cent, or less than 1 ton of soil loss per hectare, compared to the traditional ploughing; but maize yields were on average 13 per cent lower due to the land given over to the strips. The combination of vegetations trips and ridge tillage was the same as just vegetation strips within the period of evaluation but it was hoped that they would reduce scouring of the soil from one edge of the terrace to the other.
- In any case the productive benefits of the soil conservation were not perceived during the three year evaluation of this trial.
- Planting the second crop without tillage was only feasible if weeds were eliminated by applying herbicide usually glyphosate.

Source: ICRAF Annual Report, 1996

4.3.3 Integrated Nutrient Management

Definition

Soil is a fundamental requirement for crop production as it provides plants with anchorage, water and nutrients. A certain supply of mineral and organic nutrient sources is present in soils, but these often have to be supplemented with external applications, or fertilisers, for better plant growth. Fertilisers enhance soil fertility and are applied to promote plant growth, improve crop yields and support agricultural intensification.

Fertilisers are typically classified as organic or mineral. Organic fertilisers are derived from substances of plant or animal origin, such as manure, compost, seaweed and cereal straw. Organic fertilisers generally contain lower levels of plant nutrients as they are combined with organic matter that improves the soils

physical and biological characteristics. The most widely-used mineral fertilisers are based on nitrogen, potassium and phosphate.

Optimal and balanced use of nutrient inputs from mineral fertilisers will be of fundamental importance to meet growing global demand for food (International Food Policy Research Institute, 1995). Mineral fertiliser use has increased almost fivefold since 1960 and has significantly supported global population growth — Smil (2002) estimates that nitrogen-based fertiliser has contributed an estimated 40 per cent to the increases in per capita food production in the past 50 years. Nevertheless, environmental concerns and economic constraints mean that crop nutrient requirements should not be met solely through mineral fertilisers. Efficient use of all nutrient sources, including organic sources, recyclable wastes, mineral fertilisers and biofertilisers should therefore be promoted through Integrated Nutrient Management (Roy et al, 2006).

Description

The aim of Integrated Nutrient Management (INM) is to integrate the use of natural and man-made soil nutrients to increase crop productivity and preserve soil productivity for future generations (FAO, 1995a). Rather than focusing nutrition management practices on one crop, INM aims at optimal use of nutrient sources on a cropping-system or crop-rotation basis. This encourages farmers to focus on long-term planning and make greater consideration for environmental impacts.

INM relies on a number of factors, including appropriate nutrient application and conservation and the transfer of knowledge about INM practices to farmers and researchers. Boosting plant nutrients can be achieved by a range of practices covered in this guide such as terracing, alley cropping, conservation tillage, intercropping, and crop rotation. Given that these technologies are covered elsewhere in this guidebook, this section will focus on INM as it relates to appropriate fertiliser use. In addition to the standard selection and application of fertilisers, INM practices include new techniques such as deep placement of fertilisers and the use of inhibitors or urea coatings¹⁷ that have been developed to improve nutrient uptake.

Key Components of the INM Approach Include:

- Testing procedures to determine nutrient availability and deficiencies in plants and soils. These are:
 - i. Plant symptom analysis – visual clues can provide indications of specific nutrient deficiencies. For example, nitrogen deficient plants appear stunted and pale compared to healthy plants
 - ii. Tissue analysis and soil testing – where symptoms are not visible, post-harvest tissue and soil samples can be analysed in a laboratory and compared with a reference sample from a healthy plant
- Systematic appraisal of constraints and opportunities in the current soil fertility management practices and how these relate to the nutrient diagnosis, for example insufficient or excessive use of fertilisers
- Assessment of productivity and sustainability of farming systems. Different climates, soil types, crops, farming practices, and technologies dictate the correct balance of nutrients necessary. Once these factors are understood, appropriate INM technologies can be selected
- Participatory farmer-led INM technology experimentation and development. The need for locally appropriate technologies means that farmer involvement in the testing and analysis of any INM technology is essential (Box 4.25).

Box 4.25 On-farm Testing of Integrated Nutrient Management Strategies in Eastern Uganda

An action research project carried out by CIAT (Centro Internacional de Agricultura Tropical) in three villages in Eastern Uganda implemented participatory on-farm testing of farmer-designed INM strategies during a two-year process. Twenty farmers representing three soil fertility management classes in the three villages were chosen by the farmer groups as test farmers for intensive monitoring of the on-farm experimentation.

During the diagnostic phase of the PLAR process farmers analysed soil fertility management diversity and resource endowment resulting in the identification and prioritisation of 12 soil fertility and management constraints. Drought was the main constraint, followed by lack of knowledge and skills on soil fertility management, low inherent soil fertility, and soil-borne diseases and pests. The high cost of inorganic fertilisers was ranked number sixth, while soil erosion and poor tillage methods were ranked seventh. During the planning phase, farmers were taken on a farmer exchange visit to meet other farmer innovators who practise some of the proposed technologies.

Farmers designed 11 experiments and they proposed data collection procedures for monitoring and evaluation. Soil samples were collected for laboratory analysis and plant growth was monitored for germination percentage, crop performance, weed management, pests and disease incidence, time of harvesting, and crop yield.

Results

Application of farmyard manure at 10 t/ha fresh weight tended to improve maize grain yield in the two years of the project. Although the grain yield increases were not significant, farmers were ready to adapt the technology at large-scale. However, the availability, quantity and quality of the manure in the area is a major constraint to wide-scale adoption of this technology. The farmers designed an experiment to evaluate various sources of phosphorous fertilisers. There were five treatments or different mixes, including a control with no fertilisers. There was significant response to the various sources of phosphate fertilisers on maize grain yield. However, capital constraints were identified as limiting factors affecting further adoption of this technology. Green manure application did not significantly improve maize yields however the mean annual dry matter (biomass) yields were significantly different. Farmers in the test area have been using green manure for more than five years. Therefore it was proposed that this technology be disseminated without any further on-farm testing.

Farmer evaluation of on-farm experiments shows that simple, inexpensive technologies requiring little labour and locally available resources have a high potential for adoption. However, bio-economic modelling studies showed that a substantial improvement in the socio-economic environment is needed to give farmers sufficient incentives to adopt more sustainable land management practices. The results support the hypothesis that systematic learning with stakeholders, and farmers perceiving economic incentives, are necessary for changing farming practices. However, the capacity of different farmers to invest in improving soil fertility management depends on access to labour, livestock, land, capital and cash at the household level. The options available to poor farmers are much more constrained than those available to the well endowed farmers who are able to invest in large-scale use of organic and inorganic sources of nutrients.

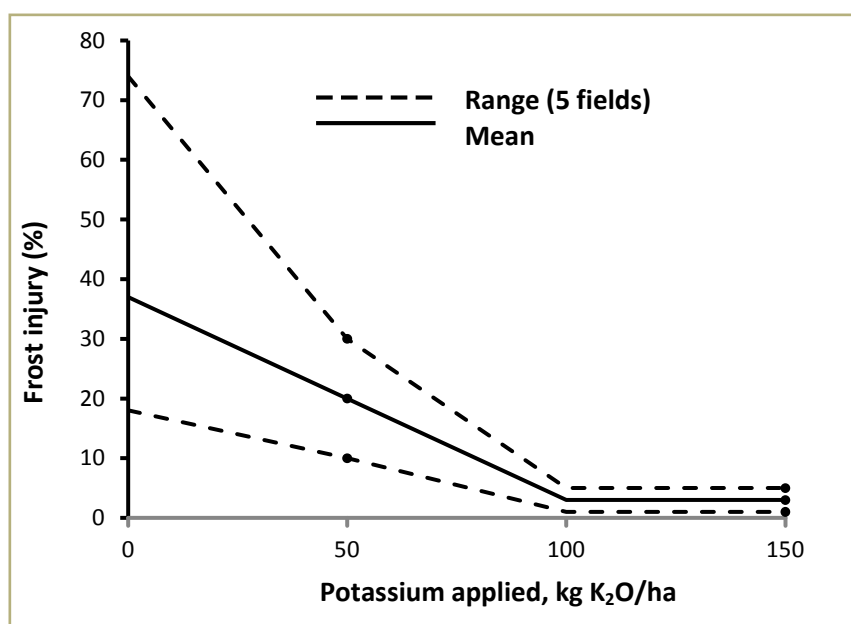
Source: Esilaba et al, 2004

The Technology and its Contribution to Adaptation

Harsh climatic conditions are a major cause of soil erosion and the depletion of nutrient stocks. By increasing soil fertility and improving plant health, INM can have positive effects on crops in the following ways:

- A good supply of phosphorous, nitrogen and potassium has been shown to exert a considerable influence on the susceptibility or resistance of plants towards many types of pests and diseases
- A crop receiving balanced nutrition is able to explore a larger volume of soil in order to access water and nutrients. In addition, improved root development enables the plant to access water from deeper soil layers. With a well-developed root system, crops are less susceptible to drought
- Under increasingly saline conditions, plants can be supplemented with potassium to maintain normal growth
- With appropriate potassium fertilisation, the freezing point of the cell sap is lowered, thus improving tolerance to colder conditions (Figure 4.14).

Figure 4.14 Effect of Potassium Application on Frost Injury to Potato Crop



Source: Grewal and Sharma, 1978

Advantages

INM enables the adaptation of plant nutrition and soil fertility management in farming systems to site characteristics, taking advantage of the combined and harmonious use of organic and inorganic nutrient resources to serve the concurrent needs of food production and economic, environmental and social viability. INM empowers farmers by increasing their technical expertise and decision-making capacity. It also promotes changes in land use, crop rotations, and interactions between forestry, livestock and cropping systems as part of agricultural intensification and diversification.

Disadvantages

As well as facilitating adaptation to climate change in the agriculture sector, the INM approach is also sensitive to changes in climatic conditions and could produce negative effects if soil and crop nutrients are

not monitored systematically and changes to fertiliser practices made accordingly. In Africa, high transport costs in land-locked countries contribute to prohibitively high fertiliser prices (FAO, 2008b). In the case of small-scale farmers these costs may represent too high a proportion of the total variable cost of production thus ruling out inorganic fertiliser as a feasible option.

Knowledge and Monitoring Requirements

INM requires knowledge of what is required by plants for optimum level of production — in what different forms and at what different timings and how these requirements can be integrated to obtain highest productivity levels within acceptable economic and environmental limits. Determining this information will require localised research but will also benefit from the cooperation of national and international agricultural research centres. Extension staff who are able to translate research data into practical recommendations will need to take account of both farmers' expertise and applicable research results. Available knowledge will need to be summarised and evaluated economically in order to provide practical guidelines for the adoption of INM by farmers that have a range of investment capacities.

Institutional and Organisation Requirements

The success of INM will depend upon the combined efforts of farmers, researchers, extension agents, governments, and NGOs. Simply providing fertilisers is not enough to support INM implementation. Appropriate policy frameworks are essential, as are market structures, infrastructure development, credit facilities and the transfer of technology and knowledge.

Costs and Financial Requirements

The main cost associated with Integrated Nutrient Management relates to the purchase and distribution of inorganic fertilisers which are affected by a range of factors (Table 4.14).

Table 4.14 Average Cost of Fertilisers Per Metric Ton in Africa

Country	Factors Affecting Cost	Cost
Mozambique	Coastal country Private market dominated by a single importer making low-volume purchases Absence of retail network resulting in low provision to rural areas Very high transportation costs and poor road infrastructure No local manufacturing or blending facilities Low fertiliser demand and consumption	\$ 554
Malawi	Land locked country Fertilisers make up one of the four largest markets in the country. Net importer with some local production Government plays central role in importation and delivery through public tender Choice of port (South Africa, Tanzania or Mozambique) greatly affects cost and availability High transport costs due to high fuel prices and poor road infrastructure Subsidised fertiliser programme with farmer voucher scheme Excessive importer, wholesale, and retail margins	\$ 495

Contd...

Ghana	Coastal country All fertilisers imported Privatised market dominated by three major importer-wholesalers Well-organised distributors and dealers No direct import duties or sales tax Market in growth phase Market price competition robust Predominantly ship (from international suppliers) and truck transport (from Nigerian suppliers and to distributors) High storage costs at ports High inland transport costs	\$ 386
-------	---	--------

Source: Chemonics, 2007

Organic fertilisers provide a low-to-no-cost technology for improving soil fertility as long as they can be produced and used within a relatively close distance.

Barriers to Implementation

An insufficient availability of credit at an affordable price is frequently mentioned as a constraint on fertiliser use. Access to mineral fertiliser may be limited in rural or underdeveloped areas due to high import prices and high transport costs. A lack of adequate infrastructure for distribution and conservation can also present a barrier for access and use. In addition, fertilisers have a limited shelf-life and may be in high demand (leading to shortages) in peak seasons if appropriate planning is not put in place. Competition for organic resources may be high in areas where crop residues are used for fuel and animal feed.

Opportunities for Implementation

A largely untapped source of potential fertiliser is urban waste. Although the quality of fertiliser produced from urban waste does not compare to commercially produced fertiliser, the sludge¹⁸ contains nitrogen, phosphorous, potassium and other micro-nutrients. Utilising urban waste for agricultural lands near urban centres puts to good use a material that otherwise would be disposed via costly means (Gruhn et al, 2000). Farmers associations and extension services provide an opportunity for production and dissemination of information on the most cost-effective and appropriate technologies.

Real Examples of Application

Box 4.26 Promotion of Integrated Nutrient Management in India

India is the third largest producer and consumer of fertilisers in the world after China and the USA. Some major initiatives have been taken to promote the balanced and integrated use of fertilisers in India. The Indian government is promoting the soil test-based balanced and judicious use of chemical fertilisers, bio-fertilisers and locally available organic manures, such as farmyard manure, compost, Nadep compost¹⁹, vermi compost²⁰, green manure and press mud, to maintain soil health and its productivity. The Centrally Sponsored Scheme on Balanced and Integrated Use of Fertilisers, since subsumed under the Macro Management of Agriculture Scheme, provides for the promotion of soil test-based application of chemical fertilisers, strengthening of soil testing facilities in the country and setting up of compost plants for conversion of biodegradable city waste into organic manure. At present, there are 609 soil-testing laboratories in India. These include 487 static and 122 mobile laboratories under the state governments and the fertiliser industry with an annual analysing capacity of 6.7 million soil samples. Under the scheme, soil health cards are being issued by the state governments to the farmers for advising them on the use of correct and balanced use of fertilisers for maximum efficiency and profitability.

Box 4.27 Managing the Nutrient Balance of Organic Coffee Farms in Nicaragua

Small-holder coffee farms in Nicaragua and much of Central America and Mexico have very low productivity, on average 0.5 tons of green coffee per hectare. This low productivity occurs across most small-holder coffee farms not just organic ones. All small holder farms are managed with shade, usually legume trees. Organic farms apply a liquid biofertiliser made from fermented manure, molasses and milk, plus moderate amounts of compost (usually less than 10 tons per hectare). At the same time the farmers suffer considerable variations in productivity from one year to the next. The productivity may be 0.8 ton/ha one year, and then only 0.3 t/ha the next. This is often correlated with variations in climate (Baker and Hagggar, 2007), the susceptibility to climate variation is exacerbated by the poor health and nutrition of the plants. It was known that fertiliser application levels were low but analysis indicated that farmers were exporting more nutrients in the coffee sold than they were applying to the coffee, as the biofertiliser contained very little in terms of nutrients and the quantities of material to make compost is severely limited (Hagggar and Soto, 2010). One of the fundamental concepts of nutrient management is that fertilisation levels must minimally replace those nutrients exported in the harvest otherwise you are mining the soil fertility and productivity will inevitably decline. In the light of these finding a process was designed to enable farmers and the extension agents from their cooperatives to support them in developing effect nutrient management that will sustain or improve production. In summary these are:

- For each ton of coffee cherries produced, approximately 3 kg of nitrogen, 1kg of phosphate and 4 kg of potash are removed from the coffee field
- If the coffee pulp is returned to the field about half of these nutrients are also returned. The coffee pulp should be returned to the field as quickly as possible as the nutrients are quickly leached out, especially the high content of potash
- To replace the remaining nutrients two tons of compost should be applied to the coffee for every ton of green coffee sold from the farm. The material for this compost should come from outside the farm. More exact calculations can be made dependent on the source materials for making the compost (such as manure and crop waste)
- The use of firewood from the shade trees also represents are large drain on the nutrients in the system, at very least the ashes from the firewood should be returned to the coffee plantations either directly or mixed in compost.

Several organic cooperatives in Nicaragua are now using this system to ensure that farmers are applying adequate amounts of fertiliser. Where centralised compost production facilities are being established this also serves as a means for the cooperatives to calculate how much compost they need to produce to compensate the export of nutrients in the coffee they are exporting to Europe and America. Although developed for organic producers, this system has also been successfully used to ensure minimal levels of fertilisation by conventional producers who have indicated they have seen more sustained yields.

Source: Hagggar and Soto 2010

4.4 Sustainable Crop Management

Crop productivity will not only be affected by changes in climatically related abiotic stresses (i.e. increasing temperatures, decreasing water availability, increasing salinity and inundation) and biotic stresses (such as increases in pests and diseases), but also changes in the atmospheric concentration of CO₂, acid rain and ground level ozone. Hence a key challenge is to assess how crops will respond to simultaneous changes

and the full range of possible stresses. Responding to unpredictable environments will require advances in crop research and the adoption of appropriate technologies based on principles of sustainable production and resource conservation.

4.4.1 Crop Diversification and New Varieties

Definition

The introduction of new cultivated species and improved varieties of crop is a technology aimed at enhancing plant productivity, quality, health and nutritional value and/or building crop resilience to diseases, pest organisms and environmental stresses. Crop diversification refers to the addition of new crops or cropping systems to agricultural production on a particular farm taking into account the different returns from value-added crops with complementary marketing opportunities. Major driving forces for crop diversification include:

- Increasing income on small farm holdings
- Withstanding price fluctuation
- Mitigating effects of increasing climate variability
- Balancing food demand
- Improving fodder for livestock animals
- Conservation of natural resources
- Minimising environmental pollution
- Reducing dependence on off-farm inputs
- Depending on crop rotation, decreasing insect pests, diseases and weed problems
- Increasing community food security.

Description

New and improved crop species can be introduced through two different processes:

- Farmer experimentation with new varieties. Farmers have introduced new and improved species over centuries, mainly in regions that constitute world centres of cultivated crop diversification, such as Meso-America, the Andes, Africa and parts of Asia, in response to environmental stress conditions. There are many thousands of existing varieties of all of the important crops, with wide variation in their abilities to adapt to climatic conditions. Agricultural researchers and extension agents can help farmers identify new varieties that may be better adapted to changing climatic conditions, and facilitate farmers to compare these new varieties with those they already produce. In some cases farmers may participate in crossing select seeds from plant varieties that demonstrate the qualities they seek to propagate to develop new varieties with the characteristics they desire.
- The introduction of new crop species to diversify the crop production systems needs to take into account the following inter-related categories:
 - iii. Availability and quality of resources including irrigation, rainfall and soil fertility.
 - iv. Access to technologies such as seed, fertiliser, water, marketing, storage and processing.
 - v. Household related factors covering food and fodder self-sufficiency requirement as well as investment capacity.

- vi. Price and market related factors including output and input prices as well as trade policies and other economic policies that affect these prices either directly or indirectly.
- vii. Institutional and infrastructure related factors covering farm size and tenancy arrangements, research, extension and marketing systems and government regulatory policies.

How this Technology Contributes to Climate Change Adaptation

Breeding new and improved crop varieties enhances the resistance of plants to a variety of stresses that could result from climate change. These potential stresses include water and heat stress, water salinity, water stress and the emergence of new pests. Varieties that are developed to resist these conditions will help to ensure that agricultural production can continue and even improve despite uncertainties about future impacts of climate change. Varieties with improved nutritional content can provide benefits for animals and humans alike, reducing vulnerability to illness and improving overall health.

The aim of crop diversification is to increase crop portfolio so that farmers are not dependent on a single crop to generate their income. When farmers only cultivate one crop type they are exposed to high risks in the event of unforeseen climate events that could severely impact agricultural production, such as emergence of pests and the sudden onset of frost or drought. Introducing a greater range of varieties also leads to diversification of agricultural production which can increase natural biodiversity, strengthening the ability of the agro-ecosystem to respond to these stresses, reducing the risk of total crop failure and also providing producers with alternative means of generating income. With a diversified plot, the farmer increases his/her chances of dealing with the uncertainty and/or the changes created by climate change. This is because crops will respond to climate scenarios in different ways. Whereas the cold may affect one crop negatively, production in an alternative crop may increase.

Advantages

The process of farmer experimentation and the subsequent introduction of adapted and accepted varieties can potentially strengthen farmers' cropping systems by increasing yields, improving drought resilience, boosting resistance to pests and diseases and also by capturing new market opportunities. To make the products of the research process more relevant to the needs of smallholder farmers, research organisations are increasingly engaged in participatory research in recognition of its potential contribution to marginal areas with low agricultural potential. There is a need to identify crops and varieties that are suited to a multitude of environments and farmer preferences. Participatory approaches increase the validity, accuracy and particularly the efficiency of the research process and its outputs. Researchers are better informed and can better inform about the traits that should be incorporated in improved varieties. Participatory processes also enhance farmers' capacity to seek information, strengthen social organisation, and experiment with different crop varieties and management practices.

Crop diversification provides better conditions for food security and enables farmers to grow surplus products for sale at market and thus obtain increased income to meet other needs related to household well-being. Crop diversification can enable farmers to gain access to national and international markets with new products, food and medicinal plants. Diversifying from the monoculture of traditional staples can have important nutritional benefits for farmers in developing countries and can support a country to becoming more self-reliant in terms of food production. Diversification can also manage price risk, on the assumption that not all products will suffer low market prices at the same time. Compared to producing monocultures, management techniques for diversified crops generally consist of more sustainable natural resource practices.

Disadvantages

Farmer experimentation using only native varieties can limit the range of benefits and responses that may be found amongst the materials being tested, although local adaptation and acceptance are ensured. At the same time, problems can arise with the introduction of exotic species (from other origin centres) that after being introduced turn into pests. There are several examples of introduced species that have escaped control becoming pests or agricultural weeds (Ojasti, 2001; Hall, 2003).

A limitation of crop diversification is that it may be difficult for farmers to achieve a high yield in terms of tons per hectare given that they have a greater range of crops to manage. In terms of commercial farming, access to national and international markets may be limited by a range of factors including government policy including subsidies, the price and supply of inputs, infrastructure for storage and transportation, amongst others. Farmers also face risk from poor economic returns if crops are not selected based on a market assessment. For example, drought tolerant crop varieties may fetch a low market price if there is not sufficient demand.

Knowledge and Monitoring Requirements

Plant breeding requires know-how and investment in terms of human and financial resources as well as time. It may take a number of years to create a new variety with improved features and an additional number of years for it to be introduced into the market and taken up by farmers.

Before contemplating any introduction, a rigorous security assessment should be conducted. This involves compiling an inventory of varieties by crop, including varieties currently used by farmers, as well as new varieties not yet available to farmers for testing. It is important to get an overview of the strengths and weaknesses of current agricultural and seed systems and an in-depth understanding of the root causes of any current and potential stresses. Fundamentally, a decision to introduce new varieties needs to be founded on sufficient evidence that new varieties offer promising opportunities, and, equally, that their introduction will not expose farmers further to increased risk.

It is important to monitor and evaluate (with farmer participation) the performance of new varieties, report results and recommend next steps and changes to improve processes. It is also important to provide detailed information on yields and production conditions.

In making decisions about diversification, farmers need to consider whether income generated by new farm enterprises will be greater than the existing activities, with similar or less risk. While growing new crops or raising animals may be technically possible, these may not be suitable for many farmers in terms of their land, labour and capital resources. Moreover, markets for the products may be lacking. Therefore preliminary feasibility and market studies are recommended before crop diversification selection is implemented.

Institutional and Organisational Requirements

In order to support farmer innovation, communities have to be linked to research programmes and should have access to research products. These links might be direct or through intermediary organisations such as NGOs and development organisations. In all cases, these links have to be made explicit and institutionalised. Support for the decentralised selection by farmers of preferred varieties (as well as their production and marketing) should be seen as part of a wider set of interventions to decentralise service delivery to farmers.

Institutional recommendations include establishing farmers' committees in order to synchronise diversification on neighbouring farms or plots that share common ecosystems. The committee exercises some authority by establishing the most appropriate crop portfolio and can provide a body that supports local farmers to access financing and technical support. Production can also be coordinated in relation to market demand, either staggering to provide a stable supply or coinciding to make a bulk sale. Government policy supporting diversification is key to facilitating access to inputs and technical skills and building national markets and developing links to external markets.

Costs and Financial Requirements

Costs of farmer experimentation are generally low, but results may only have local applicability. Capital investment will relate to the purchase of new seed varieties (if not available 'wild' locally) and labour time. Where farmers are implementing a project initiated by an external agency, capital costs for training, technical experts and field staff, on farm trial equipment (an experimental plot may be established), and site visits may also be required. In a project in Mexico, estimated total costs of a five-year project involving around 1,000 farmers came to around \$300,000 (Smale et al, 2003).

Financial requirements of diversification revolve around the costs involved in researching the species to be planted and training in the management of diversified systems. Preliminary feasibility and market research need also to be considered in the financial requirements. Infrastructure (such as transport and storage) and marketing costs should also be considered.

Barriers to Implementation

The main barrier to introducing new and improved crop varieties through farmer experimentation is the misconception that local species have low productivity. In the same vein, several communities in developing countries have lost ancient knowledge about resistant species.

The main barrier to diversification is market demand which can lead farmers to produce fewer crops or monocultures and to rely on chemical inputs. In turn, this can increase vulnerability of both the agricultural system itself to external factors such as climate change, and also the farmer to price fluctuations.

Opportunities for Implementation

Opportunities for new and improved crop varieties arise where attractive native species can be developed for sale on national and international markets. By implementing market development strategies and integrating various actors across and within the input-supply, production, sale/storage, and marketing stages of the value chain the production, profitability and competitiveness of crops can be increased. Opportunities may also arise for innovative partnerships between producers, research institutes and the private sector.

Real Examples of Application

Farmer experimentation on improved varieties of beans in Honduras have reduced the spread of diseases and therefore avoided drops in crop productivity. Participative development processes have increased access to and adoption of improved varieties for small farmers (Rosas 2001). In Central America, there are already other experiences of participative improvement of beans and maize, and there is an increasing interest from farmers, organisations and donors (Rosas 2001).

Box 4.28 Selection of Resistant Varieties of Potatoes (*Solanum* spp) for Seeds

Potato is the third most important food crop in the world after rice and wheat. It is a major carbohydrate present in the diet of hundreds of millions of people in developing countries and fundamental to the diets of populations in countries across South America, Africa, Central Asia and Asia (International Potato Centre 2010). The potato yields more nutritious food more quickly on less land and in harsher climates than any other major crop: up to 85 per cent of the plant is edible human food, while for cereals the figure is around 50 per cent (International Potato Centre, 2010).

The selection of crop varieties that are resistant to hostile climates allows agricultural activities to continue, even in extreme climate scenarios that are (i) unexpected due to extreme climate variability resulting from climate change; (ii) expected by early warning systems; or (iii) expected according to seasonality. In this sense, the same technology can be applied to different scenarios.

For the cultivation of native potatoes resistant to droughts, frost and heavy rainfall (excess of water but not flooding), tubers for botanical 'seeds' are selected based on the following criteria:

- Disease-free
- Preferably of a medium size
- Sturdy and with a good appearance
- With a large number of eyes (meristem tissue).

Traditionally, the selected tubers are stored separately from the product for consumption, for use in the next farming season.

Selecting varieties highly resistant to both droughts and high humidity creates the right conditions to deal with two of the most regularly occurring climatic scenarios caused by climate change. This reduces the risk of losing entire plantations, thus guaranteeing the availability of a minimum quantity of potatoes, a strategic food for people in developing countries. This technology also provides the opportunity for potato farmers to produce a surplus for the local market and thus earn more income to cover basic needs.

A limitation of this technology that is worth bearing in mind is that native varieties do not yield as much as genetically improved varieties, the volume and weight of which are greater (tons per hectare). Native varieties can produce as much as 10 t/ha, specialists say the average is 7 t/ha (Medina, 2010; and Torres, 2010), whereas other varieties produce more than 10 t/ha. However, the genetically improved varieties are far less resilient to extreme changes in weather conditions.

An awareness of the following is required to implement this technology:

- The genetic variability of native varieties
- Principles of experimentation in the field
- The climate variability in the area
- The value of diversity as a way of reducing risks, particularly in mountain ecosystems.

Also required is a peasant community or farmers' organisation that is respected in the area and has sufficient organisational skills to sow a large genetic diversity of crops. To achieve success, the technology should be promoted based on legal arrangements between the different actors. If at all possible, it should be implemented through an organisation in which experts come together to manage and generate local native varieties.

Source: CCTA, 2006

Box 4.29 Crop Diversification to Cope with Drought in Zimbabwe

For the last 30 years Zimbabwe has experienced dramatic losses in agricultural production resulting in critical food and fuel shortages. Coupled with the economic and political constraints, drought and climate change are testing the limits of agricultural production in Zimbabwe. In rural Zimbabwe, and specifically in the pilot project area Chiredzi district, drought is becoming an increasingly common occurrence. With approximately 70 per cent of Zimbabwe's population deriving their livelihoods from subsistence agriculture and other rural activities, the most noticeable effects of these droughts are the devastating impacts on household food security and the livelihoods of the poor.

In response to the problems outlined above, the project, Coping with Drought and Climate Change in Zimbabwe, is working to enhance the capacity of agricultural and pastoral communities in Zimbabwe to adapt to climate variability and change. One of the main targets of the project is to increase the number of farmers growing a mix of more than four crops including (sorghum, pearl millet, open pollinated variety (OPV) maize, groundnuts, cowpeas and cassava) to at least 60 per cent. The project is encouraging replication of optimised crop production through farmer field schools (FFS). Farmer field schools are being used in the project as a learning platform for farmers to increase learning and improve production strategies on the ground. Exchange visits for neighbouring farmers, public awareness campaigns and tours by policy makers are some of the tools planned to encourage the replication of best practices. The optimised crop pilots through this initiative have the potential to benefit about 6,600 households in the Chiredzi district, and many thousands more households at the national level.

Key Lessons Learned:

- **Develop institutional capacities and policy frameworks at national and local levels:** effective local and national government leadership and institutional and legal framework are needed to coordinate and guide adaptation. Strong local institutions are also a critical success factor for adaptation. For example, the presence of Chiredzi Research Station is quite strategic in the development of new technologies relevant to the biophysical conditions of the district and beyond. But the institution needs resources and human capacity to carry out this role.
- **Use bottom-up and participatory processes in project design:** bottom-up project design and participatory processes are crucial for strong ownership and adaptation responses acceptable to the local and cultural context.
- **Identify adaptation responses on the basis of assessments/analysis and evidence:** the climate risk and vulnerability assessments revealed the hazards profile, dominant livelihood strategies, dominant land use options and the sensitivity of the livelihood systems to past and future climate change scenarios. Drought was ranked as the most important hazard and, crop failure, livestock deaths and loss of income were identified as the most important drought related risks in the project area. Future climate change scenarios for the project area showed rising temperatures and possible modification of the rainfall pattern, but not necessarily drier conditions. Downscaled climate change scenarios for the project area suggested that climate change could also bring some opportunities (heavy rainfall events) that need to be captured by project beneficiaries.
- **Learn from past interventions:** building on past interventions, the project has resisted the temptation to re-invent the wheel. Crop trials have focused on extending the work of Chiredzi Research Station, SEDAP, the Challenge Programme and NGOs working in the area.

Contd...

- **Farmer-managed demonstrations are an effective way of trying adaptation measures:** in the project, farmers have been exposed to a range of strategies within the crop sector, and also some outside crops. Farmer managed demonstrations are the best way to do this, since it will make it possible to answer important evaluation questions, on: what works, why and under what circumstances. Such information will be policy relevant for up-scaling promising adaptation strategies.
- **Make monitoring and evaluation a priority:** monitoring and evaluation is crucial but challenging. Evaluating project impact on protecting/improving livelihoods against the effect of drought requires taking the (dynamic) climate baseline into account. This can be done via monitoring of conditions in a control group.

Source: Adaptation Learning Mechanism, 2011

4.4.2 Biotechnology for Climate Change Adaptation of Crops

Background

Water stressed already affects 1.5 to 2.0 billion people. In addition to increasing drought, elevated CO₂ and ozone levels, climate change will also bring greater flooding of low-lying lands and increased flooding and runoff from tropical storms resulting in salinity changes and waterlogging. Conventional crop breeding for tolerance to these effects has had considerable success but is slow and largely limited to exploiting the existing genetic variation in crop plants and their very close relatives. Biotechnology and genetic engineering give us the prospect of making more dramatic changes to crop responses to stress than is possible with conventional breeding and making them more rapidly.

Very impressive success in terms of pest control and yield improvements have been seen globally with genetically modified versions of soy, maize and cotton produced for insect pest resistance and/or herbicide tolerance since their first introduction in 1996 (see Box 4.30 for the Indian experience). More moderate results have been seen with transgenic alfalfa, canola, papaya and squash. To date these commercialised genetic modifications have involved genetically simple (single or double gene) traits. A major reason for the relatively slow progress in conventional breeding responses to the stresses related to climate change arises from the fact that plant adaptation, for example to drought or salinity effects, are not likely to be single gene changes. Whole metabolic pathways or cascades of pathways are likely to be involved. Making such changes is a challenge for biotechnology-supported breeding as much as for conventional breeding and even the most promising biotechnology-supported crop plant products are only now reaching large-scale field testing by farming communities. No drought tolerant transgenic crop variety has yet been released. Nevertheless, the underpinning research and development process has considerable scale and momentum, with invaluable techniques moving into more common use and a wide suite of technologies and products are under development which will have exponentially increasing impacts on agricultural strategies in the near future. Of course these technologies are relatively new and are surrounded by considerable concerns as to their potential long-term impacts, safety and the shifts that their adoption may bring to the power of the agro-industrial complex in traditional seed markets.

Definition

Breeding for improved performance under environmental stresses involves activities which accumulate favourable alleles (different forms of a gene) which contribute to stress tolerance. Biotechnological

contributions to crop adaptation to climate change do not only, or even mainly, concern the placement into the crop of one or more genes from an organism with which the crop could not normally breed (i.e. genetically modified crops). Biotechnological tools focus on providing the ability to directly detect and transfer genes of interest from other plant lines or organisms into the crop of interest without the continuing need to use the appearance or stress response of the plant (its phenotype) as a proxy for the presence of that gene. Phenotyping (measurement of the response of a plant line in a given environment) is still a vital part of the selection process but when a genetic region shown to be conferring an adaptive advantage has been identified, it can be transferred (even across species barriers) much more rapidly and efficiently than has been possible up to now.

Superior genes or alleles can often be found within other lines or races of the same crop and their efficient accumulation can be greatly speeded by molecular breeding where the presence of desirable genes or alleles can be directly and immediately identified, even in seeds or very young plants not exposed to the stress in question. More complex are marker-assisted backcrossing (MAB) and marker-assisted recurrent selection (MARS) techniques, allowing exactly identified pieces of DNA (individual alleles, genes or qualitative trait loci (QTLs) to be included in the desired plant line while minimising the transfer of other, less desirable, genes. Whole genome sequences are now available for soybean, maize, rice, sorghum and recently potato and high throughput 'next-generation sequencing' means that this process is rapidly accelerating, allowing the sequencing of large and complex genomes of crops such as wheat and barley. Desirable genetic loci identified in one genome can be quickly searched for in others (more detailed definition of the terms are given in Table 4.15).

Table 4.15 Terms Related to Biotechnology

Genetic Engineering (GE): Manipulation of genetic material of an organisms using recombinant DNA technology
Transgenic or Genetically Modified Organism (GMO): A plant produced by GE where the inserted genes come from a different species
Cisgenic: A GMO plant produced by GE where the incorporated genes/alleles are from other varieties of the same species
Marker-assisted backcrossing (MAB): Marker-assisted selection to introgress precisely the donor segment into the breeding line followed by marker-assisted backcrossing to recover the desired parent genome
Marker-assisted recurrent selection (MARS): Marker-assisted crossing scheme using multiple parent lines aimed at producing superior genotypes though capturing the effects of various genomic fragments with desirable QTLs, from the different parent lines. (Not possible with conventional breeding)
Molecular breeding (MB): The use of genetic tools such as DNA markers in traditional breeding (increases selection efficiency and reduces the length of breeding cycles)
Quantitative trait loci (QTLs): regions of the genome associated with complex quantitative traits governed by several large-effect and some smaller-effect genes. Transferring whole QTLs can help produce stable trait transfers.

Source: based on Varshney et al, 2011

How to Technology Contributes to Climate Change Adaptation

Genes that confer a measure of abiotic stress tolerance can be obtained from germbank collections, wild relatives of the crop, or from other organisms known to perform well under water deficit/excess or high salinity or temperatures. Boxes 4.31 and 4.32 give examples of the identification and integration of drought tolerance traits into two major global staples, rice and maize. Careful use of the molecular breeding tools described above have enabled a three to five-fold increase in rice yields and a five-fold increase in the yields of the best maize lines. These materials are being actively disseminated into breeding lines across Asia and Africa now and, just as importantly, they have been passed to commercial seed companies for the production of superior hybrid lines.

There is a great deal of activity within the major biotechnology life sciences companies and the agricultural research institutes and academic institutions on transgenic research for drought-prone environments (Ortiz et al, 2007 and Varshney et al, 2011). In the developing world, China, Brazil and India are clear leaders. The international donor community is supporting work in this area through the Consultative Group on International Agricultural Research (CGIAR) and in particular through the Generation Challenge Programme in which partners from the CGIAR institutions such as the International Rice Research Centre (IRRI) or the International Maize and Wheat Research Centre (CIMMYT) work with leading ARI and ARS institutes in developing countries. In addition to the plant lines coming out of these collaborations, the Genomics and Integrated Breeding Platform being developed by this programme will provide the technical suite of tools to enable any breeder to utilise these new technologies on-line. In addition, 'communities of practice' are under construction to provide the peer support which will be required for their efficient utilisation.

Much of the initial work has been with the plant genetics 'guinea-pig' Arabidopsis, however, benefits for field crops are rapidly emerging. For example the HRD gene in transgenic rice has improved water use efficiency and the ratio of biomass produced to the amount of water used, through enhanced photosynthesis and reduced transpiration (Karaba et al, 2007). Correlation of drought tolerance with root architecture (spread, depth and volume) has been examined in cowpea (South Africa, West Africa and India), rice (India) and beans (Central and South America). Other modifications are further from commercialisation (Table 4.16).

Table 4.16 Biotechnology Products Showing Longer-term Promise for Adaptation to Climate Change

Product	Trait	Function	Reference
Drought tolerant rice	HARDY (HRD) gene from Arabidopsis, reducing transpiration and enhancing photosynthetic assimilation	Reduced transpiration, increasing biomass/water use ratio, adaptive increase of root mass under water stress	Karaba et al, 2007
Drought tolerant tobacco (model)	Delayed drought-induced leaf senescence	Retained water content and photosynthesis resulting in minimal yield loss under drought (30% normal water requirements)	Rivero et al, 2007
Drought tolerant maize	Expression of glutamate dehydrogenase (gdhA) gene from E.coli.	Germination and grain biomass production under drought increased	Lightfoot et al, 2007 Castiglioni et al, 2008

Contd...

Drought tolerant maize	Enhanced expression of phosphatidylinositol-specific phospholipase by ZmNF-YB2 reducing stomatal conductance and so leaf temperature and water loss	Grain yield increases through reduced wilting and maintenance of photosynthesis under drought	Nelson et al, 2007
Salt tolerant rice	A QTL (Saltol) associated with drought resistance	Allows close to normal yield under high salinity situations (Bangladesh)	IRRI, 2010

Advantages

If biotechnology solutions can be delivered to farmers which mitigate the harmful effects of climate change there is great potential for maintaining food and fibre production in a degrading environment and for expanding the farmable area into currently marginal environments. This is not to imply that environmental remediation is unnecessary but it helps to provide a buffer on its urgency. The major benefit from molecular breeding to date is the speed with which multiple traits can be identified, captured and incorporated into plants and then be tested for stability and efficacy. This has increased exponentially in the last 15 to 20 years. Genetic engineering technologies allow us to utilise capacities outside the range normally available in our crop plants. Because gene insertions can now be targeted and checked in ways that were not previously possible, we can have a higher confidence in the safety of the new plant lines and can be sure that other functional plant genes have not been disrupted by the insertion. Box 4.30 lists some of the existing benefits of genetically modified cotton in India. We can expect similar scale benefits from a whole range of molecular breeding (including genetic engineering) products in the short to medium-term future.

Disadvantages

Drought and flooding are unpredictable. Ensuring that the developed plants perform well in a wide range of environmental conditions is a challenge that will require even deeper understanding of the molecular basis of responses to stress. As with other areas of modern technology, molecular breeding is becoming more and more complex and inaccessible as a science for those of modest means. The financial investment needed for efficient molecular breeding is high and companies are recouping their investment through higher seed prices and selling their material only as hybrids, effectively preventing replanting any of the seeds produced. On one hand this ensures quality control in seed purity, on the other hand it creates low autonomy on the part of the farmer. Concerns over loss of crop biodiversity have had a mixed history. India for example now has more than 750 registered Bt cotton varieties, around the same as were available nine years ago when the genetic modified Bt trait was introduced, but there is no doubt that these varieties have a narrower genetic base than formally – *Gossypium arboreum* previously covered some 40 per cent of the cotton area – and of those areas which were *G.hirsutum*, 60 per cent was in a range of varieties and only 50 per cent in hybrids. Now over 95 per cent of the country is growing a limited range of *G.hirsutum* hybrids. This concentration of advanced breeding material seems likely to continue, if only because the manpower and regulatory costs of producing and releasing substantially novel plant lines requires large markets to support the investment marginalising niche market varieties and land races.

Knowledge Requirements

The knowledge requirements of biotechnology solutions for farmers or extension service providers are relatively low. But, as can be seen from Box A, like any technology advance, an enabling environment

is necessary for benefit maximisation and can sometimes be generated by it. Over-expectation of bioengineered crops has been a problem internationally, for which the seed industry must take some responsibility. Given the seed price implications, it is important the seed industry and extension services give farmers an accurate picture of the extent to which such crops can accommodate adverse environmental conditions and what growth and yield can be expected in local environments.

The limited access of public and developing country breeding programmes to these technologies is being addressed by the Generation Challenge Programme's molecular breeding platform (GIBS). This is a brave attempt to put these high-tech tools in the hands of small-scale breeders.

Costs

There have been very different farmer cost experiences with existing bioengineered crops globally depending on the regulatory systems in place. Where private seed companies have been able to monopolise the market they have capitalised it with either farmer agreements forbidding seed saving and imposing a technology fee in addition to the increased seed cost (for example, in the USA and Australia). Where this was impractical, such as in India, the seed sector forced a monopoly through the production of only hybrid seeds. Prices began at six to ten times that of non-biotech seed but gradually declined to three to four times because of court requirements and increasing competition. China enforced competition from the beginning and had less seed price inflation. However, even in countries where seed prices were very high, the average balance of financial benefit still rested with the farmer. After a brief period of adaptation around 60 to 80 per cent of the financial benefit of the seed tends to go to the farmer and about 10 per cent to the technology developer, with the balance going to the supply chain. Many of the biotechnology responses to climate change are public sector developments intended for free or 'at cost' dissemination and are aimed at subsistence farmers with very limited ability to pay for improved inputs, particularly in the marginal environments likely to be first affected by climate change. However, the reality of the global seed distribution system make it likely that the commercial sector will be the most efficient disseminator of seed and the guardian of their purity, provided they are given some proprietary rights. Prices will then be set based on the average advantages to farmers, as in other sectors of the marketplace.

There are rather few publications on the economic impacts of biotechnology products on climate change adaptation. Alpuerto et al (2009) undertook an analysis of salinity and phosphorous tolerance in rice where the cumulative benefit to Bangladeshi farmers using marker assisted breeding rather than conventional breeding are forecast to be US\$ 800 million for salinity tolerance and US\$ 450 million for Phosphorus deficiency if conventional breeding takes 5 years longer than MAB, which is a conservative estimate. The medium term impact of the work described here and the many other products which are slightly less advanced but are in the pipeline (see Table 4.16 for examples), is expected to be dramatic.

Barriers to Implementation

The global crop breeding community has found it more difficult than expected to use the outputs of molecular breeding research in its various forms for the rapid development of improved crops for poorer farmers. Even within crop species, genome structure and gene orders have proved to be more variable than expected. The prevalence of polygenic traits with strong genetics/environment interactions have been more marked than was foreseen, making successful expression of the valued trait after intra or inter-specific transfer more elusive than had been hoped. This is slowing (and deepening) research by all organisations (including commercial companies) in this area.

Molecular breeding is not proving to be either faster or cheaper than conventional breeding, though its worth has already been demonstrated for simple traits. The generally polygenic nature of the traits necessary for the amelioration of climate change-induced shifts in the environment, makes this more difficult still. However, unlike conventional breeding, the knowledge gained with molecular breeding is incremental and will enable much more effective, productive, targeted and rapid crop development over time. Trait development is expensive and high quality seed lines are costly to maintain. As with other sections of the seed sector, effective variety/hybrid development and dissemination will depend on the value capture mechanisms available to the players in the seed chain. Properly designed, there is no reason why these mechanisms should delay the delivery of significant benefits to farmers. In the specific area of GMOs we are likely to see continued extremely high costs of regulation, significantly delaying plant provision and significantly increasing costs to farmers and pushing ownerships rights strongly into the hands of larger, often multi-national, companies. It is probably true that this regulatory burden has led to most genetically modified crop dissemination in the developing world starting in the informal sector and products only receiving regulatory approval in retrospect. This is not desirable but seems likely to continue and expand while current regulatory regimes are in place.

Opportunities for Implementation

These yield stabilising or enhancing technologies are likely to be taken up very quickly by farmers, most particularly where heat/drought/salinity is clearly moving against them over a series of seasons. Seed companies will not be slow to exploit the opportunities offered though it is likely that many of the best parental lines will emerge from public sector programmes.

Real Examples of Application

Box 4.30 Genetically Modified Insect-resistant Cotton in India

Genetically modified insect-resistant (Bt) cotton was formally released in 2002 though there had been large areas of informal production before then. Despite being effective for control of only a limited spectrum of cotton pests (most, but not all, of the cotton fruiting body feeding caterpillars) adoption was meteoric. Nine years later 6.8 million farmers planted 9.4 million hectares of Bt cotton hybrids – virtually the whole national production. Within four years of its introduction, insecticide use on cotton halved (from 46 per cent of India's insecticide consumption in 2001-2 to 25 per cent in 2005-6) and average profits approximately doubled (increases of US\$250/ha). For five consecutive years after 2005 India produced over 5.1 million tons of cotton versus its pre-Bt record of 3 million tons and became a major net exporter for the first time. The insect-control by Bt was itself a major factor, but so was the seed quality control introduced with the new hybrids. From three hybrids with one company in 2002, there are now some 780 Bt varieties from 34 companies and now several different genetic traits. Bt seed prices were initially very high at 1,350 Indian Rupee (INR) per 450 gram packet but declined with competition (and regulation) closer to the 650-INR price of non-Bt seeds. The increased profitability resulted in the purchase of better pesticides for the rest of the pest complex, new planting, and better weeding. In short, the biotechnological solution to one major production constraint changed the economics of production so radically that other investment resulting in higher productivity became possible and worthwhile.

Source: <http://cotton247.com/news?storyid=2160> and Qaim et al 2010

Box 4.31 Drought-tolerant Maize for Asia

This work, led by CIMMYT from the International Centre for Research in the Semi-Arid Tropics (ICRISAT), is developing drought-tolerant maize inbred lines for Asia. Drought tolerance from African maize lines has been combined with locally adapted Asian maize. A number of genes are implicated (the trait is polygenic) and marker assisted selection (MARS) has been used to move the yields under drought from the current 2 t/ha closer to the theoretical maximum of 13 t/ha. Work is ongoing in China, Thailand, the Philippines, Vietnam and India and is feeding into the Bill and Melinda Gates project on Drought Tolerant Maize for Africa. The top developed line (CML444) is already the top parent for drought tolerant lines in India and has been used under the Syngenta Foundation's Affordable, Accessible, Asian (AAA) Drought Tolerant Maize project which produced hybrids generating up to 10 t/ha under modest rainfall of 500-600mm annually.

Source: <http://dtma.cimmyt.org/> and <http://www.cimmyt.org/fr/what-we-do/newsletter/37-2008/152-asian-maize-network-tackles-drought>

Box 4.32 Drought-tolerant Rice for Asia

The International Rice Research Institute (IRRI) has been working for a number of years on drought tolerance in rice. The discovery of the drought resistance quantitative trait loci and its integration into rice lines in China and India under the CGIAR's Generation Challenge Programme has lifted yields under severe drought from 0.5 t/ha to 1.5 t/ha. The trait is water uptake related but surprisingly not root-length related. This is a good example of molecular breeding producing a very valuable success without necessarily understanding the mechanism of action of the trait introduced. The best lines are now yielding 2.8 tonnes/ha under drought and India's Department of Biotechnology and the All India Co-ordinated Rice Trail system has them under evaluation in five states and the outputs will feed into the Global Rice Partnership. The Bill and Melinda Gates Foundation is supporting wide testing of these rice lines in Nepal, Thailand and in Africa and there should be formal releases in India (from the University of Agricultural Sciences in Bangalore) in 2013.

Source: <http://irri.org/partnerships/networks/strasa/stresses/drought-tolerant-rice>

4.4.3 Ecological Pest Management**Definition**

Ecological Pest Management (EPM) is an approach to increasing the strengths of natural systems to reinforce the natural processes of pest regulation and improve agricultural production. Also known as Integrated Pest Management (IPM), this practice can be "defined as the use of multiple tactics in a compatible manner to maintain pest populations at levels below those causing economic injury while providing protection against hazards to humans, animals, plants and the environment. IPM is thus ecologically-based pest management that makes full use of natural and cultural processes and methods, including host resistance and biological control. IPM emphasises the growth of a healthy crop with the least possible disruption of agro-ecosystems, thereby encouraging natural pest control mechanisms. Chemical pesticides are used only where and when these natural methods fail to keep pests below damaging levels" (Frison et al, 1998; 10).

Description

The basis of this natural method of controlling pests is the biodiversity of the agroecological system. This is because the greater the diversity of natural enemy species, the lower the density of the pest population, and as diversity of natural enemy species decreases, pest population increases (Pesticide Action Network North America 2009).

The key components of an EPM approach are:

Crop Management: Selecting appropriate crops for local climate and soil conditions. Practices include:

- Selection of pest-resistant, local, native varieties and well adapted cultivars
- Use of legume-based crop rotations to increase soil nitrate availability thereby improving soil fertility and favourable conditions for robust plants that better face pests and diseases
- Use of cover crops, such as green manure to reduce weed infestation, disease and pest attacks²¹
- Integration of intercropping and agro-forestry systems
- Use of crop spacing, intercropping and pruning to create conditions unfavourable to the pests.

Soil Management: maintaining soil nutrition and pH levels to provide the best possible chemical, physical, and biological soil habitat for crops. Practices include:

- Building a healthy soil²² structure according to the soil requirements of the different plants (such as deep/shallow soil levels or different mineral contents)
- Using longer crop rotations to enhance soil microbial populations and break disease, insect and weed cycles
- Applying organic manures to help maintain balanced pH and nutrient levels. Adding earthworm castings, colloidal minerals, and soil inoculants will supplement this. Microbes in the compost will improve water absorption and air exchange
- Soil nutrients can be reactivated by alleviating soil compaction
- Reducing soil disturbance (tillage) – undisturbed soil with sufficient supply of organic matter provides a good habitat for soil fauna
- Keeping soil covered with crop residue or living plants.

Pest Management: using beneficial organisms that behave as parasitoids and predators. Practices include:

- Releasing beneficial insects and providing them with a suitable habitat
- Managing plant density and structure so as to deter diseases
- Cultivating for weed control based on knowledge of the critical competition period
- Managing field boundaries and in-field habitats to attract beneficial insects, and trap or confuse insect pests.

IPM strategies can exist at various levels of integration. Note that integration at all four levels are not common (Frison et al, 1998; 11):

- Control of a single pest on a particular crop
- Control of several pests on the same crop

- Several crops (and non-crop species) within a single production unit (farm)
- Several farms in a region (area-wide pest management).

These practices, if well implemented, result in systems that are:

- Self-regulating, maintaining populations of pests within acceptable boundaries
- Self-sufficient, with minimal need for 'reactive' interventions
- Resistant to stresses such as drought, soil compaction, pest invasions
- Capable of recuperating from stresses.

Contribution to Climate Change Adaptation

Worldwide public attention has been focused on the importance of EPM since the United Nations Conference on Environment and Development held in Rio de Janeiro in June 1992. Agenda 21, the blueprint for action prepared by the conference, recognised pesticide pollution as a major threat to human health and the environment worldwide and identified IPM as a key element in sustainable agricultural development (Frison et al, 1998; 9).

EPM is a biotechnology belonging to the denominated 'clean' technologies which combines the life cycle of crops, insects and implicated fungi, with natural external inputs (i.e. bio-pesticides) that allows a better guarantee of good harvesting even in difficult conditions of pests and diseases that emerge with the temperature and water level changes (increase of relative atmospheric humidity and runoff) typical of climate change. Thus, it is a biotechnology for facing uncertainty caused by climate change.

EPM contributes to climate change adaptation by providing a healthy and balanced ecosystem in which the vulnerability of plants to pests and diseases is decreased (LEISA, 2007). By promoting a diversified farming system, the practice of EPM builds farmers' resilience to potential risks posed by climate change, such as damage to crop yields caused by newly emerging pests and diseases.

Advantages

With the EPM approach, farmers can avoid the costs of pesticides as well as the fuel, equipment and labour used to apply them. A 22-year trial comparing conventional and organic corn/soybean systems found that organic farming approaches for these crops use an average of 30 per cent less fossil energy (Pimentel et al, 2005). Although this can cause a slight drop in productive performance, the risk of losing an entire crop is reduced dramatically.

There are also reports that production levels have increased when there has been a reduction in the use of pesticides (Pesticide Action Network North America 2009). This is the case when there are specific controllers for a determined pest, for example, in West Africa the introduction of the wasp has been a spectacular control of the slug of cassava, thus saving the staple food crop for millions of Africans (FAO, 1996a).

Disadvantages

There are very strong pests for which the 'biological controller' has not yet been identified (i.e. an insect that destroys it). When these pests emerge it is common for producers to turn to pesticides. EPM is not easy

to implement and requires substantial knowledge and monitoring for the combined components of the system to produce success. Perhaps the biggest drawback to the EPM approach is that biological control is not a 'quick fix'. In most cases, biological controllers will take several years to successfully establish a population and begin making a significant contribution. In addition, no single biological controller works in every situation. A controller that works well in one soil type, for example, may not work at all in another soil type. In the long run, more than one type of biological controller may have to be used to achieve uniform control across a variety of different situations and land types.

Knowledge and Monitoring Requirements

Knowledge is required on (i) pests and their natural enemies, (ii) effective and economic means of producing natural enemies, (iii) interactions between different means of pest control. Information on the various technological options that may be used to deal with pests and diseases is also required for the implementation of this technology. Multidisciplinary training on EPM for farmers, researchers and extension workers can help support transition to an EPM system. Early warning systems that allows for information on the population behaviour of insects, fungi and bacteria that could become plagues due to climatic variables (for example, a temperature increase) are also a useful tool for EPM implementation and monitoring. Box 4.33 provides a description of how Farmer Field Schools can be used as a model for rural education.

Box 4.33 Farmer Field Schools: A Model Approach for Farmer Education on EPM

Through farmer field schools, farmers are trained to make an analysis of their agro-ecosystem. In this way, they become aware of the pest–predator balance and of the damaging effect of pesticides on such a balance. They learn that it is better and more profitable to work with nature rather than against it. Farmer field schools have become a very popular approach and have been adopted by both NGOs and governments, on a small and a large scale. Their comparative advantage relies on a skilful incorporation of several principles:

- Learner-centred, field-based, experiential learning
- Observation, analysis, assessment, and experimentation over a time period sufficient to understand the dynamics of key agro-ecological and socio-ecological relationships
- Peer-reviewed individual and joint decision-making based on learning outcomes
- Capacity-building in leadership, social capital and empowerment.

Source: LEISA, 2007

Institutional requirements

Structures that enable farmers to organise themselves so as to jointly implement the proposed solutions are also required. Collective action can increase the successful development and implementation of EPM. Growers' cooperation can help reduce the costs of EPM implementation. In addition, better linkages between research and extension, more extension services and private consultants, and improved monitoring can all contribute to better coordination and feedback, increasing the viability and impacts of the process.

Strong efforts in the area of communication with farmers are required so that they appreciate the benefits of applying this approach. Communication should be primarily focused on showing the range of advantages

of this technology in comparison with other available options (such as longer-term sustainability and no environmental damage). Public sector agencies, such as ministries of environment, should lead on these initiatives.

Costs and Financial Requirements

A national-scale IPM programme in Nicaragua implemented by CATIE in collaboration with seventy local service providers (such as NGOs, producer organisations, technical service providers, government extension agents), trained over 300 extension agents. These extension agents in turn trained over 8000 farmers but probably reached at least 15,000 farmers through collaborators applying the techniques to farmer groups not directly attended by the programme. Farmers' pesticide use declined by between 30 to 70 per cent, but incidence of the major pests was reduced, and crop yields slightly increased. The combined cost of the training programme was about US\$ 6.6 million over five years, but was considered to have generated a net benefit of approximate US\$ 1.8 million due to reduced costs of production and increased yields (Guharay et al, 2005) (see Figure 4.15).

Figure 4.15 IPM Vegetable Production in Nicaragua



Source: CATIE, 2004

Barriers to Implementation

Major constraints to the development and adoption of EPM programmes fall into four categories:

- Technical: lack of studies and complexity of EPM
- Economic: competing simplicity and apparent efficacy of chemicals; lower prices for EPM-produced goods (cosmetic damage); high cost of selective pesticides; lack of fiscal policy that favours EPM

over pesticide use; high perceived risk if spraying is not carried out; failure to consider long-term advantages). A major obstacle to the implementation of this technology is that farmers generally prefer commercial pesticides because they are easier to apply and manage

- Institutional (poor linkages between research and extension; lack of extension services, monitoring services, private consultants)
- Educational (lack of understanding of EPM by farmers/extension agents, lack of EPM specialists) (Frison et al, 1998; 16-17).

EPM is complex and for farmers to understand and adopt EPM strategies they frequently have to change their whole pest control philosophy (Frison et al, 1998; 21). There is also a common misconception that pesticides are essential for high yields.

Opportunities for Implementation

In agricultural production systems where the environment is relatively free of polluting elements (such as pesticides), and pests and diseases are becoming progressively more aggressive, conditions for EPM development are better. This is because there is no need to 'clean' the environment first in order to conduct research into which biological controllers are required. When EPM is used, farmers can benefit from the opportunity to sell their goods as healthy organic products that can fetch a higher market price.

Real Examples of Application

Box 4.34 Large-scale Ecological Pest Management in Indonesia

Since 1989, the Government of Indonesia has been undertaking an ecologically-based pest management programme to overcome environmental problems caused by the over-use of pesticides. These environmental problems include acute and chronic human pesticide poisoning; animal poisoning and contaminated agricultural products; destruction of beneficial natural parasites and pest predators; and pesticide resistance in pests (Achmadi 1991; Oka 1995; Pimentel et al. 1992; and Antle and Pingali, 1994). The programme altered the predominant government policy of pest control from a unilateral method, depending solely on pesticide, to a combination of various control tactics to manage pests, including synchronised planting, crop rotation, natural predators, and pesticides. The programme works directly with frontline agricultural extension workers and a large number of farmers' groups across the country building their skills in ecology-based methods where decision-making and field management are based on agro-ecosystem analysis and hands-on fieldwork.

Oka (1995) reported that rice farmers who implemented the Integrated Pest Management (IPM) programme had been able to reduce the use of pesticides by approximately 56 per cent and increase rice yields by approximately 10 per cent. The Indonesian IPM National Programme Monitoring and Evaluation Team (1993) argued that IPM farmers would increase their incomes by approximately 50 per cent. Feder et al (2004a and 2004b), on the other hand, doubted that the IPM programme has actually made a difference.

Source: Resosudarmo 2008

Box 4.35 Mobilising Integrated Pest Management (IPM) to Control the Cassava Mealy Bug in Africa

A notable ecological pest management success story in Africa has been the control of the cassava mealy bug. When the cassava mealy bug, together with the cassava green mite, first appeared in Africa in the early 1970s, they caused widespread damage and loss and the livelihoods of millions of people were threatened. Predators and parasitoids that were specific to the mealy bug were discovered in 1980 in South America and, following rigorous screening in the UK, these natural enemies were introduced into Africa. After mass-rearing at the International Institute of Tropical Agriculture, the first releases took place and monitoring was initiated. The results were astonishing. Three years after the first release, one of the parasitoids (*Epidinocarsis lopezi*) was found in 70 per cent of all cassava fields in more than 200,000 km² in southern Nigeria. In 1985 this programme was expanded into the Africa-Wide Biological Control Programme and by 1990 *E. lopezi* had become established in 25 of the countries where cassava is cultivated. The biological control of cassava mealy bug has proved to be ecologically and economically sound, with a benefit/cost ratio of 178 to 1 (Mengech et al, 1995). The main reason for the high ratio is that biological control is a self-sustaining strategy and requires only a single, low-cost input.

Source: Frison et al, 1998; 18

Box 4.36 Planting of Fruit Trees in and around Crop Fields to Attract Predatory Birds in India

Farmers of the West Garo Hills (State of Meghalaya, India) plant fruit bearing plants like *Bridelia retusa*, *Dendrophthoe falcata*, *Morus macroura* and *Sapium baccatum* in terraces, sometimes in home gardens and jhum fields. These plants attract predatory birds by providing shelter and food. The birds eventually keep pest populations down by feeding on the different kinds of insect pests, mainly larvae, caterpillars and nymphs. Though no-one can identify who started this method, the farmers unanimously agree that its development is linked with the traditional activity of hunting. A long time ago, while hunting in the forest, farmers noticed that some birds prefer particular plants, and that these birds were also seen to feed on caterpillars as well as small insects. Those farmers tried planting these plants near the crop fields, to see whether the birds would feed on the insect pests. These methods are now commonly practised. The farmers' philosophy about this method is simple: "We arrange food and shelter for the birds; in return they take care of our pests."

Source: Sinha, Singha, and Choudhury, 2007

Box 4.37 Push-Pull Technology in Kenya

Kenya's International Centre of Insect Physiology and Ecology (ICIPE) and Britain's Rothamsted Research collaborated with partners in Eastern Africa to develop the Push-Pull technology. The technology involves intercropping silverleaf desmodium, a fodder legume, with maize, napier and Sudan grass to provide both immediate and long-term benefits. Aromas produced by the desmodium repel (push) pests like the maize stemborer while scents produced by the grasses attract (pull) the stemborer moths and encourage them to lay eggs in the grass instead of in the maize. Napier grass produces a gummy substance that traps the stemborer larvae so, once they hatch, only a few survive to adulthood, thus reducing their numbers. Desmodium roots produce chemicals that stimulate germination of striga seeds, but then prevent them from attaching successfully to maize roots. The striga eventually dies and the number of seeds in the soil is also reduced. Besides being a good ground cover, desmodium is a nitrogen-fixing legume that improves soil fertility.

Contd...

Agnes Ambuvi used to graze three zebu cows on weeds growing along roadsides and footpaths. Now with her napier grass and desmodium providing quality fodder, she has two new cows that produce 15 litres of milk per day, earning about 2,520 Kenyan shillings (\$35) per week. She can meet most of her household expenses including school fees, food, and clothing. Agnes has learned how to prepare farmyard manure for her maize field, minimising the need for expensive synthetic chemical fertilisers. Push-Pull also promotes biodiversity by supporting a variety of plant and animal species on the farm.

Source: Khan et al, 2008

4.4.4 Seed and Grain Storage

Definition

Seed security is key to the attainment of household food security among resource poor farmers in developing countries (Wambugu et al, 2009). Good storage helps ensure household and community food security until the next harvest and commodities for sale can be held back so that farmers can avoid being forced to sell at low prices during the drop in demand that often follows a harvest. While considerable losses can occur in the field, both before and during harvest, the greatest losses usually occur during storage. Therefore the basic objective of good storage is to create environmental conditions that protect the product and maintain its quality and its quantity, thus reducing product loss and financial loss.

There are two reasons for food storage: domestic security and maintaining value prior to sale. Farmers may not accept improvements which incur costs when storing primarily for home consumption because an improvement in the quality of a food produced for home consumption does not achieve a higher monetary value for the farmer.

Description

In order to reduce the amount of food lost, the environment in the store needs to be controlled so as to lower the possibility of:

- Biological damage by insects, rodents and micro-organisms
- Chemical damage through acidity development and flavour changes
- Physical damage through crushing and breaking.

Good storage thus involves controlling the following factors: temperature, moisture, light, pests and hygiene. Table 4.17 (overleaf) offers an overview of the storage condition requirements of some food commodities.

Table 4.17 Storage Characteristics of Selected Food Commodities

Commodities	Moisture/Humidity	Temperature/Light	Other
Cereals and pulses	Can be stored below their safe moisture level for periods of a year or more. Do not raise moisture levels.	Under a wide range of temperature.	n/a
Seed for sowing	Moisture levels need to be low. 1 per cent decrease in moisture content below 14 per cent double storage time. Maximum drying temperatures of 35°C. Full sun drying is not recommended.	Cool storage is necessary. A 5°C decrease in temperature doubles storage time.	Seed harvested when not fully ripe will lose its viability sooner than mature seed.
Oil-bearing products	Keep moisture below 7% because fungal growths above that level.	High temperature and exposure to light accelerates rancidity	n/a
Root and tuber crops	Keep humidity low to avoid rotting	Ventilation is needed to avoid rotting. Yams can be stored for four months at normal temperatures (25-35°C). Potatoes for only five weeks as they are sensitive to sunlight. Chill rooms for storage on a large scale. Store should be ventilated during coolest part of the day and isolated during hottest time.	To increase storage life, use special treatment called 'curing' which consists of letting tubers grow layers of cork cells around the surface
Fruit and vegetables	n/a	Keep better when cooled but damaged by freezing. Simple evaporative air-cooled cabinets allow small farmers to store them. Underground storage in pits and cellars is used.	Surface waxing or wrapping prevents the spread of rot from one fruit to another. Keep in CO ₂ rich atmosphere

Source: based on IT Publications and UNIFEM, 1995

Most developing countries are in the tropics. They are often in areas of high rainfall and humidity, which are ideal conditions for the development of micro-organisms and insects, causing high levels of deterioration of crops in store. Thus, an assessment of different storage methods has to be undertaken before investing in one. Existing local methods are usually low-cost so adapting what is already there, rather than introducing new technology, is often a more realistic economic option for households. Traditional and improved storage techniques are presented in Table 4.18.

Table 4.18 Traditional and Improved Storage Methods

	Suitable for	Capacity/ Storage Time	Cost/Materials
Traditional Storage Methods			
Earthenware pots and gourds	Cereals, beans, groundnuts, dried fruit and vegetables and seed material	5-30 litres Up to 1 year	Very low
Leaves	Dried fruits, vegetables and treacle	Variable Up to 1 year if unopened	Low Banana leaves, string of sisal or other plant material
Bark	Cereals, particularly paddy and shelled maize	100 kg Up to 3 months	Labour
Baskets	Cereals, pulses, oilseeds, potatoes	Variable Up to 9 months	Low but considerable labour involved Reeds, grasses, palm leaves, bamboo
Sacks	Cereals, pulses and dried fruit	Up to 60kg Up to 1 year	Low Jute, sisal and cotton
Basket silos	Cereals and pulses	Up to a tonne Up to 1 year	Local material, time spent on construction Elephant grass, reeds, sorghum stalks
Roof storage	Cereals	Variable Up to 1 year	Wood for platform and labour Wood for platform
Maize cribs	Maize	Variable Up to 6 months	Labour and materials Variable
Underground pits	Cereals, pulses and root crops	Variable Up to 1 year	Labour Grass, straw, chaff and clay
Clamp storage	Tubers	Up to 500kg Up to 6 months	Labour Grass, straw
Small storehouses	Cereals and pulses	Variable Up to 1 year	Labour and materials Variable
Earth silos	Cereals and pulses	Variable Up to 1 year	Labour Earth, straw
Improved storage techniques			
Plastic bags	Sowing seed, cereals, pulses, groundnuts, copra	Up to 60 kg 6 to 9 months	Fairly high

Contd...

	Suitable for	Capacity/ Storage Time	Cost/Materials
45-gallon metal drums	Cereals, pulses and seeds	50-200 litres Up to 1 year	Low, depending on availability Oil drums and water tanks
The Pusa bin	Cereals and pulses	400kg to 3 tons 6 to 12 months for well-dried crops	Medium/high, skill required Mud, cement or concrete, wood, plastic
Metal silos	Cereals and pulses	Up to 5 tons Approx. 1 year	Medium/high Sheet metal
Brick silo	Cereals and pulses	Up to 5 tons Up to 1 year	Medium/high Bricks, cement, reinforcing rod, wood for moulds, sheet metal
Cement-stave silo	Cereals and pulses	Up to 10 tonnes Up to 1 year	Medium/high Cement, sand, iron and wire
Thai ferro-cement silo	Cereals and pulses	4-6 tons 9 to 12 months	Medium/high Cement, sand, aggregate, mortar plasticiser, sealant for base, paint, chicken-wire, rod, water pipe
Storage in ventilated huts	Cereals, pulses, root crops	Variable Variable	Medium/high Local building materials
Improved pit storage	Cereals, pulses, root crops	Variable Up to 1 year	Medium Metal sheet, mud/dung/straw or plastic or ferro-cement lining

Source: based on IT Publications and UNIFEM, 1995

Contribution to Climate Change Adaptation

Grain storage has been established to prepare for droughts and hunger and malnutrition (UNEP, 2010; 36). Grain storage provides an adaptation strategy for climate change by ensuring feed is available for livestock and seed stock is available in the event of poor harvests due to drought (UNEP, 2010; 62). Efficient harvesting can reduce post-harvest losses and preserve food quantity, quality and the nutritional value of the product (FAO, 2010; 3). Innovations for addressing climate change include technologies for reducing waste of agricultural produce (BIAC, 2009). In fact, the establishment of safe storage for seeds and reserves of food and agricultural inputs are used as indicators of adaptive capacity in the agriculture sector (CARE, 2010).

Advantages

The establishment of safe, long-term storage facilities ensures that grain supplies are available during times of drought (UNEP, 2010; 36). It is important to be able to store food after harvest so as not to be compelled

to sell at low prices. Appropriate storing techniques can prolong the life of foodstuffs, and/or protect the quality, thereby preserving stocks year-round.

Disadvantages

The cleaning and drying of grain for storage are essential measures. However, difficulties in achieving the desired freedom from excess moisture and foreign matter are frequently encountered. Failure to adequately clean and dry grain can lead to pest infestations. Over-drying of grains can also negatively impact seed quality. Losses of seeds from insects, rodents, birds and moisture uptake can be high in traditional bulk storage systems. Controlling or preventing pest infestation may require chemical sprays. Some markets will not accept seeds and grains treated with these chemicals.

Knowledge and Monitoring Requirements

Adopting new storage methods is likely to require technical training. For example, in addition to constructing a new silo, training or advice on maintenance, health and safety regulations, quality control and seed storage behaviour (sensitivity to light and moisture) could be needed. It is important to monitor progress, in order to resolve problems, build on developments, and record successes and failures. Socio-economic impacts should be considered, such as who benefits and how additional income or time is distributed between and within households or businesses.

Organisation and Institutional Requirements

Health and safety regulations and quality control guidelines should be elaborated by the relevant national authority. Standardised training and inspections may also be undertaken by a government agency.

Costs and Financial Requirements

Table 4.18 sets out the relative costs of traditional and modern storage technologies. Costs requirements vary between storage methods. If the produce is for consumption, rather than sale, then investing large amounts in a new technology will not prove cost-efficient. On the other hand, if the amount of food for sale increases, then the investment can be paid back over time. Calculating the existing profit and potential profit with new technology is useful for businesses to estimate this payback period. The amount people are prepared to invest in new technology may depend partly upon who owns the equipment and facilities. In some cases, farmers will invest in a new technology if they have total ownership of it while in other cases, storage may be collectively owned and so costs can be shared. Access to credit is often dependent on where people live, educational levels and on being able to raise collateral. Adopting new storage methods for low-income farmers will be possible if they are given assistance with literacy and numeracy, and possibly some kind of group training.

Barriers to Implementation

A common constraint is that produce has to be sold off immediately to pay off debts to landowners or creditors. This is the most widespread reason for deciding that investing in new storage technology is impossible. It has to be considered also that additional time input for constructing and maintaining storage facilities will be perceived as worthwhile only if the increase in income is sufficient.

Opportunities for Implementation

Before initiating technology development work, it is important to assess the need for improvements. IT Publications and UNIFEM (1995) suggest an opportunities assessment checklist that can be usefully discussed with producers during a preliminary appraisal:

- Problems with existing storage techniques
- Disadvantages of existing storage techniques greater than advantages
- Possibility of improved storage of reducing the loss of produce/possibility of increase on quality of produce for sale or consumption by better storage
- Possibility to keep surplus produce stored away rather than having to sell any extra produce immediately
- Possibility to sell any extra produce
- Increased profit through improved storage
- Time for learning improved techniques for collecting materials and making the new equipment/ money for storage materials
- Access to new technical knowledge and skills required for producing, maintaining and using the new technology
- Benefits against investment on time, money and effort in improving storage.

Case Study

Box 4.38 Experiment in Kenya – Cow Dung Ash and Airtight Storage Increase Seed Longevity

In a baseline survey carried out in Siaya and Busia Districts of Western Kenya, storage was identified as a priority problem facing onfarm seed production. About 80 per cent of the farmers produce and store their own seeds for planting in the next cropping season. Thus, a storage experiment was set up for improving the efficacy of traditional maize seed storage methods in maintaining seed viability and vigour as compared to some improved ones. The traditional methods included hanging cobs over the fireplace and storing in gunny bags with cow dung ash as the seed treatment. These were compared with seed treatment using a modern seed protectant and cow dung ash and stored in airtight containers. The results indicate that the traditional methods had the poorest performance. They had significantly lower vigour after three and six months' storage and recorded significantly higher insect damage. Seeds hung above the fireplace had the highest insect damage and this was about 99 per cent higher than the damage recorded for seeds treated with ash and stored in airtight plastic containers. Seeds hung above the fireplace also had a significantly higher moisture content increase. The best treatment was storage in airtight containers with either the modern seed protectant or cow dung ash as the seed treatment.

This study concluded that the principle of using airtight storage should be used to design low-cost seed storage containers for resource-poor farmers which will result in better seed quality. It also shows that cow dung which is freely available in most homesteads is a good seed protectant and is effective in maintaining seed quality in storage. Cow dung ash should therefore be combined with air tight storage to increase the seed longevity.

Source: Wambugu et al, 2009

Box 4.39 Improved Technologies for Reducing Post-harvest Losses in Afghanistan

In the northern region of Afghanistan, where more than half of the country's cereals are produced, many farmers store their crop in plastic and fibre bags or in farm buildings without proper flooring, doors and windows. This offers limited protection and results in significant post-harvest losses. The Government requested support from the FAO to provide silos for communities and farming households for grain storage. With funds provided by Germany, FAO implemented a project from 2004 to 2006 with the objectives of reducing post-harvest losses and enhancing the technical capacity of local tinsmiths, blacksmiths and craftsmen for construction of metallic grain silos. Seven main grain producing provinces were selected as focus areas. Technical personnel from the Ministry of Agriculture and NGOs trained 300 local artisans in the manufacture of silos, while contracts were issued to over 100 tinsmiths who built metallic silos ranging from 250 to 1,800 kilogram capacity for distribution in local communities. The project also oversaw the construction of grain warehouses for community use in 12 sites and trained beneficiaries on how best to operate and manage the facilities. It was found that the use of the metallic silos had reduced storage loss from 15 to 20 per cent to less than 1 to 2 per cent, grains were of higher quality (as protected from insects, mice and mould) and could be stored for longer. Based on the training received, tinsmiths, blacksmiths and craftsmen are now fabricating silos as a profitable enterprise.

Source: FAO, 2010; 3

Box 4.40 Diffuse Light Storage

Diffuse light storage (DLS) is a low-cost method of storing seed potatoes which has been found to extend their storage life and improve their productivity. DLS uses natural indirect light instead of low temperature to control excessive sprout growth and associated storage losses (FADR, 2010). DLS can be used to preserve any tuber seed around the world.

Provided that direct sunlight can be controlled, any kind of existing potato storage facility can be converted into DLS so it is not necessary to build a new structure. There are many design options because any design used by farmers is good as long as the DLS principle is adopted (Community Development Library, 2010). Farmers tend not to build new stores or copy demonstration stores precisely, but prefer to modify existing dwellings to meet their needs and budgets (FADR, 2010). Any changes to existing potato storage facilities for converting it into DLS should be low-cost and easily constructed so investment is more related to wages and the purchase of seeds.

While the principle that light reduces potato sprout growth has been long established in scientific literature, the International Potato Centre in Peru (CIP) has adapted the technology for use by potato farmers in developing countries. CIP tested demonstration models of DLS structures in the community of Benguet in the Philippines. Since its introduction in 1978, DLS has been rapidly adopted. The basic criteria for a DLS structure are that it has an insulated roof, translucent walls, and adequate ventilation. The adoption of the DLS in some other developing countries including Guatemala and Sri Lanka is remarkably similar (FADR, 2010).

In general, the results of DLS have had wide reaching effects within developing countries that depend on potatoes as a primary staple crop (FADR, 2010). The technology helps secure a source of tuber seeds to deal with uncertain climate conditions in which an increase or a sharp drop in temperature (frost) would increase the risk of tuber seeds deteriorating. It also controls the plagues that affect the tubers. Furthermore, a surplus can be produced so that farmers can gain access to the market and thus generate more income for other activities and to meet the needs of local people.

Source: FADR, 2010 and Community Development Library, 2010

4.5 Sustainable Livestock Management

Livestock systems in developing countries are characterised by rapid change, driven by factors such as population growth, increases in the demand for livestock products as incomes rise, and urbanisation. Climate change is adding to the considerable development challenges posed by these drivers of change. The increasing frequency of heat stress, drought and flooding events could translate into the increased spread of existing vector-borne diseases and macro-parasites, along with the emergence of new diseases and transmission models (IFAD, 2009). Appropriate sustainable livestock management practices are required so that livestock keepers can take advantage of the increasing demand for livestock products (where this is feasible) and protect their livestock assets in the face of changing and increasingly variable climates.

4.5.1 Livestock Disease Management

Definition

Livestock diseases contribute to an important set of problems within livestock production systems. These include animal welfare, productivity losses, uncertain food security, loss of income and negative impacts on human health. Livestock disease management can reduce disease through improved animal husbandry practices. These include: controlled breeding, controlling entry to farm lots, and quarantining sick animals and through developing and improving antibiotics, vaccines and diagnostic tools, evaluation of ethno-therapeutic options, and vector control techniques.

Description

Livestock disease management is made up of two key components:

- Prevention (biosecurity) measures in susceptible herds
- Control measures taken once infection occurs.

The probability of infection from a given disease depends on existing farm practices (prevention) as well as the prevalence rate in host populations in the relevant area. As the prevalence in the area increases, the probability of infection increases.

Prevention Measures

Preventing diseases entering and spreading in livestock populations is the most efficient and cost-effective way of managing disease (Wobeser, 2002). While many approaches to management are disease specific, improved regulation of movements of livestock can provide broader protection. A standard disease prevention programme that can apply in all contexts does not exist. But there are some basic principles that should always be observed. The following practices aid in disease prevention:

- Elaboration of an animal health programme
- Select a well-known, reliable source from which to purchase animals, one that can supply healthy stock, inherently vigorous and developed for a specific purpose. New animals should be monitored for disease before being introduced into the main flock
- Good hygiene including clean water and feed supplies
- Precise vaccination schedule for each herd or flock

- Observe animals frequently for signs of disease, and if a disease problem develops, obtain an early, reliable diagnosis and apply the best treatment, control, and eradication measures for that specific disease
- Dispose of all dead animals by burning, deep burying, or disposal pit
- Maintain good records relative to flock or herd health. These should include vaccination history, disease problems and medication.

Surveillance and Control Measures

Disease surveillance allows the identification of new infections and changes to existing ones. This involves disease reporting and specimen submission by livestock owners, village veterinary staff, district and provincial veterinary officers. The method used to combat a disease outbreak depends on the severity of the outbreak. In the event of a disease outbreak the precise location of all livestock is essential for effective measures to control and eradicate contagious viruses. Restrictions on animal movements may be required as well as quarantine and, in extreme cases, slaughter. Figures 4.16 and 4.17 are photos illustrating the holistic approaches to livestock disease prevention and control.

Figures 4.16 and 4.17 Holistic Approaches to Disease Prevention and Control



Left: Woman and man participants in rural training course in learning how to improve health of their goats – Sudan

Source: Courtesy to Mohammed Salih, Practical Action

Right: Man immunising goat held by woman – Bangladesh

Source: Courtesy to Zul Mukhida, Practical Action

The Technology and its Contribution to Adaptation

The major impacts of climate change on livestock diseases have been on diseases that are vector-borne. Increasing temperatures have supported the expansion of vector populations into cooler areas. Such cooler areas can be either higher altitude systems (for example, livestock tick-borne diseases) or more temperate zones (for example, the outbreak of bluetongue disease in northern Europe). Changes in rainfall pattern can also influence an expansion of vectors during wetter years and can lead to large outbreaks. Climate changes could also influence disease distribution indirectly through changes in the distribution of livestock. Improving livestock disease control is therefore an effective technology for climate change adaptation.

Advantages

Benefits of livestock disease prevention and control include: higher production (as morbidity is lowered and mortality or early culling is reduced), and avoided future control costs. When farmers mitigate disease through prevention or control, they benefit not just themselves but any others at risk of adverse outcomes from the presence of disease on that operation. At-risk populations include residents, visitors and consumers. The beneficiaries might also include at-risk wildlife populations surrounding the farm that may have direct or indirect contact with livestock or livestock-related material.

Disadvantages

Management options may interact, so the use of one option may diminish the effectiveness of another. Another critical issue is the long-term sustainability of currently used strategies. Chemical intervention strategies such as antibiotics or vaccines are not biologically sustainable. Animals develop resistance to drugs used to control certain viruses and with each new generation of vaccine a new and more virulent strain of the virus can arise (Tanji and Kielen, 2002). Small-scale producers may be negatively affected by livestock disease management if the full cost of the disease management programme is directly passed onto them with no subsidy from the government (FAO, 2003a).

Costs and Financial Requirements

Livestock disease management costs include: testing and screening, veterinary services, vaccines, training of livestock keepers and veterinary staff, and perhaps changes to practices and facilities to reflect movement restrictions and quarantines when animals are added to the herd. The costs of a small-scale mastitis control programme in Peru are shown in Box 4.41.

Box 4.41 Control of Mastitis

A low-cost technology applicable to a wide range of livestock (cattle, sheep and goats) is the control of mastitis. Mastitis is an infectious disease caused by pathogenic micro-organisms due to inadequate milking practices or blows to the udders. It is one of the diseases that cause the most financial losses in milk production. In conditions of increasing climate variability, emergence of new pests and diseases can introduce invasive organisms to the livestock environment. It is therefore essential that livestock farmers are able to identify and prevent mastitis in order to maintain healthy animals that, in turn, are more capable of withstanding adverse weather conditions such as prolonged droughts or severe frosts.

Information and monitoring requirements for the control of mastitis include:

- Producer training on testing and diagnosing mastitis, hygienic milking practices, teat sealing, treatment of clinical mastitis, control records
- Organisations or institutions must have extension farmers or technicians who are trained in the mastitis control process
- Monitoring and regular check-ups are necessary for the prevention of mastitis.

The following is also required in the application of this technology:

- The California Mastitis Test (CMT) or black background rate. This is very easy for farmers to use as readings are immediate and low cost
- Teat sealant to protect the udder against mastitis germs

Contd...

- Clean and disinfected containers, cloths and mechanical milking machines
- Milking records which should contain basic information like the name of the animal, the date, the name of the person milking the animal, the rooms examined, evidence of mastitis, density and acidity of the milk.

Institutional and organisational requirements must also be taken into account: health care institutions and producers' organisations should carry out sanitation campaigns, hold training workshops and provide technical assistance on the control of mastitis, using adequate informative materials like easy-to-read leaflets and flyers that the cattle farmers can understand and follow. Costs and financial requirements are relatively low. The CMT costs about US\$25 and can last about six months for an average of three cows per farmer. The teat sealant costs about US\$30.

In a project implemented by Practical Action Latin America in San Miguel province in the Cajamarca region of Peru, two Livestock Services Centres were formed. These centres comprised extension farmers who had participated in a training programme on livestock management, animal health, animal feed, genetic improvement, business management, and information and communication technologies. This enabled them to provide training and technical assistance in their 22 settlements or communities. At the present time, 22 extension farmers are providing more than 450 services, dealing with problems affecting the dairy cattle and providing training in their communities on mastitis control and milk analysis; hygienic milking; milk control records and dairy cattle management. This mastitis control practice was applied in 50 per cent of the dairy farms, improving the quality of the milk and increasing production by 10 per cent.

Source: Prepared by Juan Vargas from Practical Action Latin America for this guidebook

Prevention and control costs are generally evaluated against expected financial losses resulting from a disease outbreak in a cost-benefit analysis. The assumption is that increased prevention and control costs lower the expected losses by diminishing the expected scale of an infection. McInerney et al (1992) present the problem graphically as a cost minimisation problem:

$$\min C = L + E$$

Where C is total annual disease cost, L is the value of output losses, and E is the control expenditures (which themselves are a function of inputs purchased for control).

Knowledge and Monitoring Requirements

In order for producers to make decisions regarding disease management, they must understand the options that they have. These options depend on disease biology, prevention techniques, tests for infection and their costs, treatments available, market reactions, as well as industry and government programmes and policies. Disease biology includes transmission modes and rates, disease evolution (for example, length of time to infectious period), production losses associated with the disease, and mortality rate (where applicable).

Practical training for farmers should include:

- Principles of anatomy and physiology of the livestock animals
- Principles of nutrition and pasture ecology

- Animal diseases of local importance: clinical and post mortem signs, epidemiology, prevention, treatment. Applying first aid, the use of basic veterinary medicines (wound treatments, dips, anthelmintics, antibiotics, trypanocides, babesiacides, vaccines, care and storage of medicines and vaccines, and the use and care of syringes)
- The basic principles of sero-surveillance campaigns – how to draw blood and store sera.

Modelling disease outbreaks and spread can provide valuable information for the development of management strategies. Modelling involves studying disease distribution and patterns of spread to determine the scale of a problem. This information is used to develop a model that can predict the spread of disease. Disease modelling requires prior knowledge of animal population distributions and ecology, diseases present and methods of disease transmission. Modelling can be used to assess potential disease impacts and develop contingency plans.

Geographic Information System (GIS) software can play a key role in livestock disease management. The main advantage of GIS software is not just that the user can see how a disease is distributed geographically, but also that an animal disease can be viewed against other information. For example, maps that show possible impacts of climate change on rainfall patterns, crop yields and flooding. The disease presence can then be related to these factors and more easily appreciated visually. This is important in relation to managing and responding to the changes in distribution of diseases due to changing climate (FAO, 1999). The role of indigenous knowledge in livestock disease management under climate change is shown in Box 4.42 below.

Box 4.42 The Role of Indigenous Knowledge in Livestock Disease Management under Climate Change

Indigenous knowledge about livestock disease management has been shown, in certain cases, to be cost-effective, sustainable, environmentally friendly and practical. Practices include:

- Utilisation of local plant remedies for prevention and cure of diseases
- Avoiding certain pastures at particular times of the year; and not staying too long in one place to avoid parasite build-up
- Lighting smoke fires to repel insects, especially tsetse flies
- Mixing species in the herd to avoid the spread of disease
- Avoiding infected areas or moving upwind of them; spreading livestock among different herds to minimise risks; and quarantining sick animals
- Selective breeding. As an example from the arid south of Zambia, restocking and promoting the rearing of drought-tolerant goat breeds are adaptive measures already being undertaken.

Source: Niamir-Fuller, 1994; Moonga and Chitambo, 2010; Environmental Council of Zambia, 2009

Institutional and Organisational Requirements

Countries should cooperate in programmes against trans-boundary disease either through formally formed organisations or networks. Neighbouring countries often have similar production systems and disease risk profiles and will be more likely to be affected by similar climate change impacts in livestock disease. There will be mutual benefits and cost savings through joint preparedness planning. Public policies range from bounties/indemnities for infected livestock to required herd depopulation and farm decontamination, to decentralisation programmes for provision of veterinary services and drug supplies. Livestock and

animal health policy should be oriented to both the commercial and pastoral sectors and include pro-poor interventions to support the most vulnerable populations. Government investments in infrastructure (including early warning systems, roads, abattoirs, holding pens, processing plants, air freight/ports and so on), systematic vaccination, and in research and development can all contribute to providing an enabling environment for effective livestock disease management. Removing or introducing subsidies for improved management, insurance systems and supporting income diversification practices could benefit adaptation efforts (IFAD, 2009).

Barriers to Implementation

A lack of strong institutions and political will to monitor disease status effectively can produce a considerable barrier to livestock disease management. Difficulties in eradication of disease may also be exacerbated by many small-scale and backyard producers, infected wildlife, smuggling, and cockfighting (FAO, 2003). If there is no compensation for stamping out disease through slaughter, then producers, particularly small-scale producers, may be reluctant to participate. If they do participate it may mean that they no longer can afford to produce (FAO, 2003).

Opportunities for Implementation

Where the disease organism has built up resistance against vaccines or the animal has built resistance against the disease there is an opportunity for incorporating simple, high-tech genetic approaches such as selective breeding. National planning for livestock disease management also presents an opportunity to improve agricultural support services in rural areas and to incorporate indigenous knowledge into formal prevention and control plans, thereby unlocking the potential of low-cost interventions and disseminating information on traditional lessons and experiences to a wider audience. Trans-border collaboration can provide an opportunity to strengthen veterinary services and can improve the effectiveness of disease management programmes through harmonisation of prevention and control measures, such as disease reporting and surveillance.

A Real Example of Application

Box 4.43 Control of Animal Diseases Related to Climate Changes: Rift Valley Fever

There are strong correlations between Rift Valley Fever (RVF) and climate change. Heavier rainfall is leading to an increase in the emergence of mosquito species that carried the RVF disease. "The recent outbreak of Rift Valley Fever (RVF) in Madagascar in 2008 provides an example of how principles and tools such as rapid disease detection, early warning, and early response can be used for the control of emerging diseases. The virus, which causes high livestock losses and is also a severe threat to human health, was found in test samples which triggered a country wide survey of livestock and the establishment of surveillance systems. Sentinel screening of herds in 13 locations were established through the contracting of local, private veterinarians to undertake field surveillance and undertake weekly visits to communities. Mosquitoes and other samples were collected in the infected areas in order to identify vector species. To prevent human contamination, information campaigns were organised and protective equipment was distributed to professionals working in slaughterhouses. In Autumn 2008, a month after the first training, a veterinarian in a remote area launched an alert. The implementation of local measures immediately after detection of the first cases prevented the outbreak from spreading to further areas."

Source: EMPRESS, 2010

4.5.2 Selective Breeding via Controlled Mating

Definition

Genetic make-up influences fitness and adaptation and determines an animal's tolerance to shocks such as temperature extremes, drought, flooding, pests and diseases. Adaptation to harsh environments includes heat tolerance and an animal's ability to survive, grow and reproduce in the presence of poor seasonal nutrition as well as parasites and diseases. Selective breeding is a technology that aims to improve the value of animal genetic diversity. This technology can be applied to all types of livestock, including cattle, sheep, goats, alpacas and guinea pigs. As developments have been made over time in improving measurement techniques and methods for estimating an animal's genetic potential, the power and effectiveness of selective breeding as a tool has also increased. Over the last half century it has helped achieve dramatic improvements in the productivity of livestock species as well as improvements in the health and welfare of livestock and other animals.

Description

Selective livestock breeding is the systematic breeding of animals in order to improve productivity and other key characteristics. Various methods for selective breeding exist, from high-tech and costly processes such as in-vitro fertilisation or genetic engineering to more simple low-cost techniques that rely on the selection and controlled mating of animals based on observable characteristics. Key breeding traits associated with climate change resilience and adaptation include thermal tolerance, low quality feed, high kid survival rate, disease resistance, good body condition and animal morphology (Oseni and Bebe, 2010; and Hoffman, 2008). In general, developing countries have a weak capacity for high-tech breeding programmes to increase livestock adaptation (IFAD, 2009). Therefore, programmes based on controlled mating methods are likely to be more appropriate. These programmes usually do not produce immediate improvements. Improvements are usually not seen for at least one growing season, so a livestock producer must be able to incorporate long-term planning into production management strategies. Such measures could include: (i) identifying and strengthening local breeds that have adapted to local climatic stress and feed sources and (ii) improving local genetics through cross-breeding with heat and disease tolerant breeds (Hoffman, 2008).

There are three main approaches to selective breeding:

Outcrossing

Mating two animals that are unrelated for at least 4 to 6 generations back is called an outcross. This method works best when the genetic variation for a trait is high. When dominant genes are the desirable ones, outcrossing works perfectly well. One of the best advantages of outcrossing is that it hides detrimental traits by keeping them recessive. Outcrossing improves fitness traits such as reproductive ability, milk production, kid survivability and longevity.

Linebreeding

Linebreeding involves mating related animals like half-brother/half-sister, cousins, aunt/nephew, and other more distant relationships. This is usually done to capitalise on a common outstanding ancestor who appears in recent generations of the pedigree. There is a higher degree of uniformity with linebreeding than in outcrossing, and a reduced possibility of harmful genetic defects than inbreeding.

Inbreeding

This breeding method involved mating directly related animals, like mother/son, father/daughter, and full brother/full sister (full siblings). This method is used generally to create uniformity and prepotency (the ability of this process to continue) and to force out latent weaknesses from the gene pool. However, recessive genes are more of a factor than dominant genes in genetic faults, so there is a high risk producing kids with problems. Inbreeding reduces the pool of available genes and can cause some lines to become extinct. Fitness traits are especially at risk with this breeding scheme.

How the Technology Contribute to Climate Change Adaptation

Selective breeding through controlled mating enables farmers to breed animals that are more resistant to the impacts of climate change, such as sudden changes in temperature, prolonged droughts or the appearance of new diseases. It can reduce mortality rates, increase fertility rates, and can also be used to improve the quality of livestock products such as milk and fibre. As a result, livestock producers are at a lower risk from losing animals to climate change impacts and they are also able to diversify their income-generating activities by capitalising on higher-quality dairy or fibre production.

Advantages

The specific advantages of selective breeding through controlled mating include low input and maintenance costs once the strategy is established, and permanence and consistency of effect. In addition, controlled mating can preserve local and rare breeds that could be lost as a result of climate change-related disease epidemics.

Disadvantages

One of the main limitations of this technology is that selective breeding of certain genes can run the risk of reducing or removing other genes from the overall pool, a process which is irreversible. This can create new weaknesses amongst animals, particularly with the emergence of a new pest or disease. Depending on the animal traits chosen, selective breeding may not always lead to higher productivity rates.

Knowledge and Monitoring Requirements

Knowledge of current climate impacts on livestock is important for the definition of desirable traits. Where available, climate change scenarios will facilitate planning processes by providing possible future impacts on livestock animals. Livestock producers need to be trained to keep records, identify females on heat, identify key traits amongst animals, secure good quality water and feed for their livestock and build infrastructure for controlled mating. The implementing institution, or preferably the local community, must have a technician with good knowledge of the controlled mating process, capable of explaining it clearly to producers without encouraging them to reduce the number of animals they keep and recognising the need to create a nucleus of good quality livestock. It is necessary to monitor the application of this technology in each group of animals and to review progress by examining producers' records.

To apply this technology, mating pens made of adobe, stone or cattle mesh are required. Cattle mesh pens are the most expensive. Small animals can mate in wooden mating pens. Identification material such as ear tags and paint is required to monitor animals. It is also necessary to keep logbooks containing basic information on the livestock (age, gender, colour), mating data (dates, number, time), details of the offspring

(father, mother, colour and other basic data), animal culling, selling prices of meat, hides, dried meat, and fibre, among others.

Institution and Organisational Requirements

Governmental institutions can provide support to selective breeding programmes by facilitating access to information and providing technical support. It will be important for governments to coordinate closely with indigenous communities in order to benefit from knowledge accumulated over decades of traditional pastoral livestock keeping. National information systems can be used to monitor threats to breeds caused by climate change or other pressures and develop predictive modelling and early warning systems. Governments should develop policies to strengthen livestock keepers' adaptation strategies, their ecological knowledge and local institutions. Governments can provide financial incentives for breeding and raising breeds that are more resilient to climate change, promote and support marketing of products derived from these breeds, and provide infrastructure supporting selective breed production. Government institutions should also consider importing new genetic stocks with greater resistance to high temperature, for example, should the adaptative capacity of the local gene pool be limited.

Costs and Financial Requirements

The costs and financial requirements will depend on the livestock species and location. However, in general controlled breeding is a low-cost technology. If stones are locally available and can be used to build the mating pens, an average investment would come to around US\$ 30. In areas with clay soils, adobe bricks may be used, at an average cost of US\$ 90. In many cases, cattle mesh has been the chosen alternative, with an average investment of US\$ 200 for each mating pen.

Barriers to Implementation

There are knowledge gaps about how breeds react to conditions brought about by climate change. The FAO (2007a; 2006) list many species and local breeds which are already adapted to high temperatures and harsh conditions, or are reported to be resistant or tolerant to various diseases. However, many of these reports are based on anecdotal evidence rather than scientific studies, and the underlying physiological and genetic mechanisms are not well understood. This makes it difficult to predict climate change impacts or develop adaptation strategies for such production systems or breeds.

Opportunities for Implementation

Despite a lack of scientifically corroborated information, indigenous knowledge about livestock genetic diversity has been shown to provide an important knowledge base for selective breeding. Integrating indigenous knowledge into selective breeding programmes is an opportunity for the development of low-cost, locally-appropriate strategies (Moonga and Chitambo, 2010). Documentation of the indigenous knowledge of livestock keepers about animal breeds and breeding should be an integral part of the work of rural development projects, institutions and organisations because it can be a source of information about the existence of breeds that scientists have overlooked and which may have unrecognised advantages and potential. Investments in science and technology for developing new breeds and genetic types also present an opportunity for larger-scale interventions where funding is available (IFAD, 2009).

A Real Example of Application

Box 4.44 Controlled Alpaca Breeding in Peru

In the Andean highland province of Canchis, located in department of Cusco, Peru, at more than 3,800 m above sea level, peasant communities and/or associations are dedicated to breeding South American camelids, especially alpacas. These alpaca farmers each own between 30 and 120 alpacas and 90 per cent of them manage their livestock in a traditional manner. High mortality rates and low fertility rates of livestock together with increasingly colder weather spells are decreasing livestock producer income.

Practical Action Latin America implemented a project there, entitled Management of Natural Resources in High Mountain Areas (Practical Action, 2010), aimed at improving the standard of living of alpaca farmers. One of the main objectives was to develop and strengthen the technical management of alpaca breeding, for which end controlled mating pens were built with cattle mesh. The farmers received the following training:

- Construction of a mating pen made of adobe, mesh or stones
- Identification of herds by type and the reproductive status of the animals (females and males)
- Identification of breeding stock that will produce animals of a better quality with good physical and reproductive characteristics
- Identification and detection of receptive females by sexual behaviour
- Record-keeping on copulation time and male and female ear tag numbers
- Supervision and training in the application of controlled mating. That is, the females in the herd that were served first and those that previously rejected the male are submitted to a sexual receptivity control. The females that continue to express open receptivity will be served a second time and those that are still receptive will be served a third and fourth time
- Evaluating the mating campaign and determining the conception rate.

As a result, 60 per cent of the farmers applied the controlled mating processes to improve their alpacas. Alpaca fertility rates increased by more than 20 per cent. Mortality rates were reduced by 20 per cent. Both the quality of the fibre and the yield per alpaca improved. Consequently, farmers were able to increase their income by more than 100 per cent.

Source: Prepared by Nadya Villavicencio, Practical Action Latin America, for this guidebook

4.6 Sustainable Farming Systems

Farming systems are more complex than just one crop or livestock species, much of the ecological and productive resilience to climate change comes from managing a diversity of integrated production systems combining crops, livestock and trees. Mixed farming systems integrating livestock and crops, and agro-forestry systems that can mix crops, trees and livestock present these integrated farming systems.

4.6.1. Mixed Farming

Definition

Mixed farming is an agricultural system in which a farmer conducts different agricultural practice together, such as cash crops and livestock. The aim is to increase income through different sources and to complement land and labour demands across the year.

Description

Mixed farming systems can be classified in many ways. They can be based on land size, type of crops and animals, geographical distribution, market orientation, and so on. Three major categories are distinguished here (FAO, 2001).

On-farm versus Between-farm Mixing

On-farm mixing refers to mixing on the same farm, and between-farm mixing refers to exchanging resources between different farms. On-farm mixing enables the recycling of resources generated on a single farm. Between-farm mixing can be used to resolve waste disposal problems where by crop farmers use waste from animal farms for fertiliser.

Mixing within Crops and/or Animal Systems

This practice involves multiple cropping or keeping different types of animals together. For example, grain-legume association can provide grain with nitrogen. With plant inter-cropping farmers can make the most of the space available to them by selecting plants and cropping formations that maximise the advantage of light, moisture and soil nutrients. Examples of mixed animal systems include chicken-fish production where chicken waste serves as fish fodder.

Diversified versus Integrated Systems

In a diversified system some components exist as independent units. In an integrated system, maximum use is made of resources, making the system highly interdependent.

How the Technology Contribute to Climate Change Adaptation

Mixed farming technology contributes to adaptation to climatic change because the diversification of crops and livestock allows farmers to have a greater number of options to face the uncertain weather conditions associated with the increased climate variability. Mixed farming can also give a more stable production because if one crop or variety fails, another may compensate. Livestock represents a means by which families can save and invest in the future. Livestock is a walking bank of assets that can be sold during periods of need such as if crops fail due to drought or flooding.

Advantages

This technology also allows greater food security and improved household nutrition levels. In addition, farmers can generate a surplus of some products that can be sold at market. Among other benefits, this technology also allows farmers to grow fodder for livestock and poultry. An additional benefit of mixed rice-fish culture systems is that the fish may help reduce populations of existing and emerging disease vectors such as mosquitoes.

In many areas the hungry season on farms comes in the months just after the rains start when producers need to invest labour in the planting and management of crops, but before they start to produce. Conversely

grass production starts immediately with the rains, and livestock quickly gain weight and increase milk production. The high milk production in the rains can greatly help support the nutrition of farmers while they are tending their crops and waiting for harvest. The advantages of mixed farming systems for the environment are shown in Box 4.45 below.

Box 4.45 Advantages of Mixed Farming Systems for the Environment

- Mixed farming systems maintain soil fertility by recycling soil nutrients and allowing the introduction and use of rotations between various crops and forage legumes and trees, or for land to remain fallow and grasses and shrubs to become re-established;
- Mixed farming systems maintain soil biodiversity, minimise soil erosion, help to conserve water and provide suitable habitats for birds;
- Mixed farming systems make the best use of crop residues. When they are not used as feed, stalks may be incorporated directly into the soil, which may temporarily trap nitrogen, creating nitrogen deficiency. Burning the crop residues, the other alternative, increases carbon dioxide emissions; and
- Mixed farming systems allow intensified farming, with less dependence on natural resources and preserving more biodiversity than would be the case if food demands were to be met by crop and livestock activities undertaken in isolation.

Source: FAO, 1996

Disadvantages

One limitation is that production levels in mixed systems (tons per hectare, milk per animal daily, increase and reproduction rates), can be lower than in specialised systems (monoculture) (FAO, 1999). Another disadvantage is that where farmers depend on wild animal stock rather than domesticated species, they may face increased vulnerability in instances where animal population levels are affected due to climate change (for example, where livestock populations need to be trimmed).

Partly because of overgrazing, some mixed farming systems of the tropical highlands of Asia and Central Africa are among the most eroded and degraded systems of the world (FAO, 1996). Integrating crops and livestock can help improve soil nutrient and reduce the stress on farming land.

Knowledge and Monitoring Requirements

Knowledge about the phenology and lifecycles of different crops to be cultivated simultaneously (or with some time lag between them), as well as knowledge about the soil nutrients required by each of them (so they can complement each other, is required to use this technology. For example, some crops require higher levels of nitrogen, while others require more potassium. Knowledge is also required about the season in which each of the crops involved should be sown and which crop species and varieties can be grown together because of the inter-species competition.

Organisation and Institutional Requirements

The organisations promoting this technology need to have qualified technicians both in agronomy and livestock production. These organisations must identify the farmers that are familiar with the technique of multiple crops in the area and develop positive relationships with them.

Costs and Financial Requirements

As for most cases, to estimate the costs of implementing this technology the cost of wages, agricultural tools, and inputs (such as seeds and fertilisers) must be considered. Infrastructure for supporting livestock will be an added cost in crop-animal systems. The main financial needs are associated with credits for the acquisition of inputs, investment in training and in the dissemination of this technology. Investment is needed also to obtain the necessary qualitative and quantitative micro-climate information for managing the synchronisation of mixed crop cycles (phenologies).

Barriers to Implementation

The main obstacle for the implementation of this technology is farmers' reluctance since mixed farming is considered to have low productivity in comparison with monocultures which have a high yield in terms of tons per hectare (t/ha). The best way to overcome these barriers is to demonstrate mixed farming systems with better productivity levels; to disseminate the benefits of this technology, and to provide training.

Opportunities for Implementation

The main opportunity for implementing mixed farming is that it improves and guarantees the range of products a farmer has available to sell at market. One option to increase productivity while maintaining economic and environmental benefits of mixed farming is specialisation. Partnerships with specialised farms are formed to facilitate the exchange of crops and waste products from manure. For example, the traditional association between nomads and farmers reaping where nomadic cattle converts crop residues into manure for cultivation. More recent developments include partnerships between dairy farmers and vegetable growers. Similarly, in organic farming in Europe between specialised organic farms there is an exchange of secondary products and crop residues for manure (FAO, 1999).

Real Examples of Application

Box 4.46 Mixed Crop-livestock Farming and Climate Change in Africa

New research conducted by the European Commission estimates the impacts of future climate change on farm production system choice ((i) specialised crop farms, (ii) specialised livestock farms or (iii) integrated farms that own both crops and livestock) and net revenue until 2060. The results indicated that integrated farming would increase by about 6 per cent due to climate change. The net revenue of specialised crop farming was predicted to fall by as much as 75 per cent whilst the profit for integrated farming would only fall by about 10 per cent. Integrated farming should be more resilient partly because some livestock species can be raised in hot dry savannah zones, but also because diversification brings economic benefits under climate shocks. While higher temperatures could see profits fall for specialised crop farms, higher rainfall could reduce profits for specialised livestock farms. This increases the likelihood that farmers will choose to diversify their portfolio.

The results have important implications for food security: crop-only farms could become highly vulnerable whilst integrated farming could fare better. As such, policy should help farms adapt by providing support for the switch to mixed farming.

Source: EC, 2010

Box 4.47 Advantages of Mixed Farming in Southern Honduras

Small-holder farmers in Namasique and El Triunfo in southern Honduras live in a climate of alternating floods and droughts. Between a third and a half of the population are considered to be vulnerable to severe drought. With climate change rainfall is predicted to fall by 15 per cent by 2030. Between 1994 and 2003, 90 per cent of farmers reported crop losses of over 50 per cent in four or more years during that decade, with maize production averaging less than 1 t/ha and beans less than 0.4 t/ha. Those farmers who depended only on agricultural production had an income of US\$340 per year. Even then those farmers who had a commercial crop such as sesame or cashew (40 per cent of farmers) provided about half of this income. About 70 per cent of farmers had chicken or pigs that added \$35/year and \$86/year respectively in income. The few farmers with cattle (33 per cent) had considerably higher additional income of nearly \$500 per year from this source. Those farmers that only had annual crop production were the poorest families, with income from agricultural production of little more than \$100 per year, and depended on selling their labour to larger farms to survive.

Source: Haggard et al 2004

4.6.2 Agro-forestry

Definition

Agro-forestry is an integrated approach to the production of trees and of non-tree crops or animals on the same piece of land. The crops can be grown together at the same time, in rotation, or in separate plots when materials from one are used to benefit another. Agro-forestry systems take advantage of trees for many uses: to hold the soil; to increase fertility through nitrogen fixation, or through bringing minerals from deep in the soil and depositing them by leaf-fall; and to provide shade, construction materials, foods and fuel. In agro-forestry systems, every part of the land is considered suitable for the cultivation of plants. Perennial, multiple purpose crops that are planted once but yield benefits over a long period of time are given priority. The design of agro-forestry systems prioritises the beneficial interactions between crops, for example trees can provide shade and reduce wind erosion. According to the World Agro-forestry Centre, “agro-forestry is uniquely suited to address both the need for improved food security and increased resources for energy, as well as the need to sustainably manage agricultural landscapes for the critical ecosystem services they provide²⁴”. Agro-forestry is already widely practiced on all continents. Using a 10 per cent tree cover as threshold, agro-forestry is most important in Central America, South America, and South East Asia, but also occupies a large amount of land area in Africa.

Description

There are a broad range of classifications for Agro-forestry systems. These include: structural classification (composition, stratification and dimension of crops); to classification based on the dominance of components (such as agriculture, pasture, and trees); functional (productive, protective or multi-purpose); ecological; and socio-economic. Generally, however, agro-forestry systems can be categorised into three broad types: agrosilviculture (trees with crops), agrisilvipasture (trees with crops and livestock) and silvopastoral (trees with pasture and livestock) systems.

Agro-forestry is appropriate for all land types and is especially important for hillside farming where agriculture may lead to rapid loss of soil. The most important trees for incorporating into an agro-forestry system are legumes because of their ability to fix nitrogen and make it available to other plants. Nitrogen improves the fertility and quality of the soil and can improve crop growth. Some of the most common uses of trees in agro-forestry systems are:

- Alley cropping: growing annual crops between rows of trees

- Boundary plantings/living fences: trees planted along boundaries or property lines to mark them well
- Multi-strata: including home gardens and agroforests that combine multiple species and are particularly common in humid tropics such as in South East Asia
- Scattered farm trees: increasing a number of trees, shrubs or shaded perennial crops (such as coffee and cocoa) scattered among crops or pastures and along farm boundaries.

Any crop plant can be used in an agro-forestry system. When selecting crops, the following criteria should be prioritised:

- Potential for production
- Can be used for animal feed
- Already produced in the region, preferably native to the zone
- Good nutritional content for human consumption
- Protect the soil
- A Lack of competition between the trees and crops.

Table 4.19 shows five stages to the design and implementation of an agro-forestry system.

Table 4.19 Agro-forestry Diagnosis and Design

Stage	Basic Tasks
Diagnostic	<ul style="list-style-type: none"> • Definition of the land-use system and site selection • Physical characteristics (including altitude, rainfall, slopes, water supplies, soil condition, visible erosion). This is basic background for evaluating the need for agro-forestry and the local suitability of various techniques • Current uses of trees and shrubbery. This suggests the kind of subsistence products that an agro-forestry system would be expected to provide • Sales and purchases of agro-forestry products (including poles, fruit, firewood, fodder, etc.). This provides data for economic analysis, and indicates opportunities to replace purchased items or to expand sales by raising agro-forestry products • Current tree planting (including species, source of seedlings, and intended use). This shows the present state of silvicultural knowledge • Farmers' perceptions of deforestation and erosion (including any perceived impact on crop yields). This gives a sense of how critical farmers think their problems are, and indicates current awareness of agro-forestry relationships • Land and tree tenure. This shows whether farmers have a right to their trees, and therefore whether they have an incentive to plant • Current yields • Limiting constraints access to technology and finance, farmer capacities and markets • Survey of local knowledge and scope for domestication of wild food and medicinal plants.

Contd...

Design and evaluation	<p>How to improve the system?</p> <ul style="list-style-type: none"> • List potential benefits of an agro-forestry system • List agricultural production needs (meet food security, increase production to meet market demands and so on) • Adoptability considerations: social and cultural acceptance; importance of local knowledge, practice and capacity; as well as equity and gender issues • Characterise the crops desired by minimum space requirements, water and fertiliser needs, and shade tolerance • Select the trees, shrubs, or grasses to be used.
Planning	<p>If the system is temporary:</p> <ul style="list-style-type: none"> • Plan the features of soil erosion control, earthworks, and gully maintenance • Plan spacing of fruit trees according to final spacing requirements • Plan a succession of annual or short-lived perennials beginning with the most shade tolerant for the final years of intercropping. <p>If the system is permanent:</p> <ul style="list-style-type: none"> • Plan the proportion of the permanent fruit and lumber trees on the basis of relative importance to the farmer • Plan the spacing of long-term trees on the basis of final space requirements times 0.5 • Plan succession of annual and perennial understory crops, including crops for soil protection and enrichment • As large permanent trees grow, adjust planting plan to place shade tolerant crops in most shady areas.
Implementation	<ul style="list-style-type: none"> • On-farm trials of proposed agro-forestry models to analyse impacts of trees on crops, testing harvesting regimes.
Monitoring	<ul style="list-style-type: none"> • On-going study and analysis of soil nutrition, moisture, and so on • Watershed design study • Measure the inputs and outputs of the system (including yields of trees and crops, and labour requirements) • Survey of land-use • Socio-economic benefit assessment.

Source: Raintree, 1986; Martin and Sherman, 1992; FAO, 1991

How the Technology Contributes to Climate Change Adaptation

Agro-forestry can improve the resilience of agricultural production to current climate variability as well as long-term climate change through the use of trees for intensification, diversification and buffering of farming systems. Trees have an important role in reducing vulnerability, increasing resilience of farming systems and buffering agricultural production against climate-related risks. Trees are deep rooted and have

large reserves, and are less susceptible than annual crops to inter-annual variability or short-lived extreme events like droughts or floods. Thus, tree-based systems have advantages for maintaining production during wetter and drier years. Second, trees improve soil quality and fertility by contributing to water retention and by reducing water stress during low rainfall years. Tree-based systems also have higher evapo-transpiration rates than row crops or pastures and can thus maintain aerated soil conditions by pumping excess water out of the soil profile more rapidly than other production systems if there is sufficient rainfall/soil moisture (Martin and Sherman, 1992).

Trees can reduce the impacts of weather extremes such as droughts or torrential rain. For example, a combination of Napier Grass and leguminous shrubs in contour hedgerows reduced erosion by up to 70 per cent on slopes above 10 per cent inclination without affecting maize yield in central Kenya (Mutegi et al, 2008). Research has also demonstrated that the tree components of agro-forestry systems stabilise the soil against landslides and raise infiltration rates (Ma et al, 2009). This limits surface flow during the rainy season and increases groundwater release during the dry season.

Agro-forestry can also play a vital role in improving food security through providing a means for diversifying production systems (Box 4.48).

Box 4.48 Tree-based Agricultural Systems Improve Food Security and Livelihoods

By integrating trees in their farms and rangelands, farmers reduce their dependency on a single staple crop or having sufficient grass for their animals. For example, if a drought destroys the annual crop, trees will still provide fruits, fodder, firewood, timber and other products that often achieve high commercial value. A study of 1,000 farmers from 15 districts in Kenya found that fruit trees contributed 18 per cent of crop revenue, and tea and coffee contributed an additional 29 per cent of revenue (Place and Wanjiku, 2006). A study in Zimbabwe concluded that indigenous fruits provided higher returns to labour than annual crop production (Mithoefer and Waibel, 2003). A study from Nepal on the impact of agro-forestry on soil fertility and farm income showed that agro-forestry intervention nearly doubled farm productivity and income.

Source: Neufeldt et al, 2009

Advantages

Agro-forestry has a broad application potential and provides a range of advantages, including:

- Agro-forestry systems make maximum use of the land and increase land-use efficiency
- The productivity of the land can be enhanced as the trees provide forage, firewood and other organic materials that are recycled and used as natural fertilisers
- Increased yields. For example, millet and sorghum may increase their yields by 50 to 100 per cent when planted directly under *Acacia albida* (FAO, 1991)
- Agro-forestry promotes year-round and long-term production
- Employment creation – longer production periods require year-round use of labour
- Protection and improvement of soils (especially when legumes are included) and of water sources.
- Livelihood diversification
- Provides construction materials and cheaper and more accessible fuelwood
- Agro-forestry practices can reduce needs for purchased inputs such as fertilisers.

Disadvantages

Agro-forestry systems require substantial management. Incorporating trees and crops into one system can create competition for space, light water and nutrients and can impede the mechanisation of agricultural production. Management is necessary to reduce the competition for resources and maximise the ecological and productive benefits. Yields of cultivated crops can also be smaller than in alternative production systems, however agro-forestry can reduce the risk of harvest failure.

Knowledge and Monitoring Requirements

To plan for the use of trees in agro-forestry systems, considerable knowledge of their properties is necessary. Desirable information includes the uses: the climatic adaptations of the species, including adaptations to various soils and stresses; the size and form of the canopy as well as the root system; and the suitability for various agro-forestry practices. The selection of crops also requires knowledge of uses, adaptation, and market opportunities (Martin and Sherman, 1992).

It is also important to understand how trees and crops interact. In simultaneous agro-forestry systems, trees and crops can share above-ground and below-ground space. Trees and crops interact in many ways, leading to both positive and negative effects on the growth of both trees and crops. These processes, which are very complex, are related to light, water, nutrients and wind. These processes also affect the soil itself. There are also indirect interactions, for instance related to pests and diseases. Cycling of soil organic matter, nutrients and water are processes that are central to understanding the interactions in agro-forestry systems.

Knowledge is also required about the main laws and decrees that influence the management of natural resources. It is important to understand the concept of tree and land tenure, including both the formal legal system and the traditional tenure systems and to be familiar with policies related to land use, soil and vegetation, and socioeconomics, including trade and market policies. An understanding of national, regional and local development plans and programmes relevant to agro-forestry and natural resource management is also required.

Institutional and Organisational Requirements

The institutional context is essential to natural resource management and agro-forestry. The main categories of institutions with a bearing on agro-forestry are shown in Table 4.20.

Table 4.20 Key Institutions for Agro-forestry

Typology	Institutions
Government	<ul style="list-style-type: none"> Government agencies with a mandate related to agro-forestry and the function of those agencies in relation to agro-forestry and natural resource management Government agencies involved in extension programmes related to natural resource management Government administration at various levels: national, regional and local (including provincial, municipal, district and village levels).

Contd...

Non-governmental organisations (NGOs)	<ul style="list-style-type: none"> • Local, national and international NGOs involved in relevant areas such as rural development and environmental conservation • Overview of NGOs with a role in agro-forestry development, and agenda and mandate as well as programme thrusts and priorities of those organisations • Links, interactions and collaboration between NGOs, the government sector and local institutions and local people.
Private sector	<ul style="list-style-type: none"> • The private sector links and functions in the agriculture sector • Market forces and functions • Local institutions in relation to the private sector.
Community-based formal and non-formal institutions	<ul style="list-style-type: none"> • Roles and functions in agro-forestry development, including market development for agro-forestry products; and in scaling up agro-forestry innovations • Roles in monitoring and evaluation of agro-forestry programmes.
Research institutes	<ul style="list-style-type: none"> • Research institutions with agro-forestry mandate and with an emphasis on field-based research and on-farm participatory experimentation • Agro-forestry research and development links at all levels.
Training and education institutes	<ul style="list-style-type: none"> • Research and technology development • Extension programmes in training and education institutions.

Source: prepared by the authors

The policy and legal framework is of great importance for the sustainable management of natural resources. Local government and forestry authorities should be lobbied to simplify the legal processes for commercialisation of native wood and non-timber products grown in agro-forestry systems. Increased adoption of agro-forestry should be supported by government through finance. Research and training is required to match high value agro-forestry species with the right agro-ecological zones and agricultural practices (Neufeldt et al, 2009).

The implementation of the agro-forestry farming approach should be accompanied by the organisation of farmers into cooperatives in order to improve their capacity to negotiate better prices for their goods and avoid paying a percentage of their profits to intermediaries. Joining cooperatives gives farmers the status of organised producers, facilitating access to larger markets and organic and fair trade certification. As a result, farmers' income can rise significantly. Farmers should also receive training on management issues, decision-making and participation in local administration, such as participatory budget and development planning at municipal level.

Costs and Financial Requirements

In Eritrea, a large-scale five-year agro-forestry project led by the Ministry of Agriculture aimed at creating healthy and well-managed forest plantations to withstand the impacts of climate change was presented

as part of the country's NAPA strategy. The project had a total cost of just over US\$ 5 million, as detailed below:

Table 4.21 Agro-forestry Project Costs in Eritrea

Project Components	Cost (US\$)
Infrastructure/civil works (construction of roads, office, community forest nurseries)	1,150,000
Equipment and supplies (field and office equipment, hand tools, water pumps, vehicles, and so on)	1,000,000
Community development support (forest extension services)	950,000
Silviculture (seedling production and distribution)	1,100,000
Recurrent costs (Staff salaries, allowances, maintenances etc)	850,000
Total	5,050,000

Source: UNFCCC, 2008a

A five-year project included in the NAPA of Senegal aimed at promoting agro-forestry had a total budget of US\$ 258,000 for establishing community nurseries, plant growing, installation of plantations and rejuvenation of regional forests (see Table 4.22).

Table 4.22 Agro-forestry Project Costs in Senegal

Activity	Year 1 (FCFA)	Year 2 (FCFA)	Year 3 (FCFA)	Year 4 (FCFA)	Year 5 (FCFA)	Total (FCFA)	Total (US\$)
Nursery	32 million	2 million	2 million	2 million	2 million	40 million	80,000
Plant and plantation production	1 million	1 million	1 million	1 million	1 million	5 million	10,000
Regional forests	80 million	1 million	1 million	1 million	1 million	84 million	168 000

Source: UNFCCC, 2008a

Barriers to Implementation

Key barriers to the practice of agro-forestry are:

- Poor access to agro-forestry inputs/resources including land tenure, tree tenure, water, seeds and germplasm, and credit.

- Agro-forestry production or management issues relating to knowledge about agro-forestry systems, quality control, storage, processing of products, access to technical outreach services, and upfront costs versus long-term gain
- The main benefits of agro-forestry are perceived in the medium term at least five to ten years after establishment, this means that farmers must be prepared to invest in their establishment and management during several years before the main benefits are generated
- Marketing of agro-forestry products and services. Lack of access to transport, handling, processing, and marketing infrastructure, bans/restrictions on timber products, over-production, and lack of demand for products.

Opportunities for Implementation

Agro-forestry provides an excellent opportunity to promote sustainable forest management while improving income-generating opportunities for local communities. Agro-forestry can provide a more diverse farm economy and stimulate the whole rural economy, leading to more stable farms and communities. Economic risks are reduced when systems produce multiple products. Likewise, this approach prioritises conservation and rehabilitation measures such as watershed rehabilitation and soil conservation.

Real Examples of Application

Box 4.49 Introducing Cactus-based Agro-forestry Practices to the Drylands

The drylands of Ethiopia have poor vegetation cover and have a high evapo-transpiration rate that exceeds precipitation. The identification of suitable plant species that can thrive and produce yields and contribute to farming practices add to resilience. One such plant species is the cactus pear which has many possible uses and benefits, from fresh fruits and stem segments, to vegetables or livestock feed over, to pigments and sugar, or ethanol extraction. One likely option for cultivation would be the introduction of cactus pear into farmlands as hedges or intercrops with an additional advantage in mitigating the impacts of climate change. Mekelle research centre conducted an observation on an orchard of 11 cactus pear cultivars intercropped with beans. Significant biomass of cactus pear cladodes (914.63 kg) and edible fruits (268.3 kg) was produced in addition to a significantly higher bean yield (1333.3 kg) per hectare in over eight months. Because cacti are perennial plants, they will continue to grow and will yield more fruits and biomass in the following years. Bean plots with no cactus intercrops gave significantly lower yields (700 kg/ha). Intercrops had the additional benefits of trapping moisture in the trenches and this should have contributed to better use of the poor rains of the 2008 rainy season (375mm) in the area. Cactus does have the potential for hedge-row intercropping and the combination helps increase biomass produced per hectare with the added benefits of increasing the vegetation cover. The latter is relevant to drylands where the land is bare for more than 7 months before the next crop is planted. Cactus-based agro-forestry practice can therefore be considered as an adaptation option to climate change in the drylands.

Source: Belay, 2009

Box 4.50 Coffee Agro-forestry for Adaptation to Climate Change in Chiapas, Mexico

The coffee company CafeDirect and GTZ collaborated on a project to facilitate adaptation to climate change among coffee producers in Mexico, Nicaragua and Peru. The small-holder producers' members of MasCafe cooperative in Chiapas analysed the impacts on climate change on their farmers and produced an adaptation strategy. The primary impacts they perceived were:

- Increased deforestation and forest fires
- Increased incidence of heavy rainfall
- Impoverishment of soils
- Increased in pests and diseases.



Their adaptation strategy included the following elements:

- Programme of reforestation to increase shade in the coffee plantations and in the surrounding area
- Training on biological control of pests and diseases
- Production of organic compost from waste materials
- Reduce use of fire wood for drying coffee and increase capture of carbon in reforestation
- Establish solar driers to maintain coffee when raining during the harvest.

Training was provided to farmers to help them develop adaptation strategies on their own farms. The training consisted of answering the following:

- Understanding the effects of climate variation on coffee production
- Defining what are the characteristics of coffee plantations that perform better in years of drought or excess rainfall
- How does climate change affect the flowering and fruiting of the coffee?
- How do shade trees affect the impact of climate on the coffee?
- What conditions slow the development of pests and diseases?
- What measures help conserve soil fertility
- What measures conserve water sources and prevent their contamination
- What practices can we test to create coffee plantations more resilient to climate change?
- Based on this analysis with producers a programme of training and implementation of practices is developed with each group of producers. A detailed training manual was produced on how to implement this training (Schepp et al, 2010).

Source: Schepp, 2010; Schepp et al, 2010

4.7 Capacity Building and Stakeholder Organisation

4.7.1 Community-based Agricultural Extension Agents

Definition

‘Agricultural extension’ describes the services that provide rural people with the access to knowledge and information they need to increase productivity and sustainability of their production systems and improve their quality of life and livelihoods. Recent developments in agricultural policies have re-emphasised the importance of extension services²⁵. However, models of extension based on government services or private agro-dealers and service providers are not sufficient to meet the needs of farmers in less favoured areas. This is due to a number of factors including the necessity to respond to the specific technological needs of farmer in different agroecological zones, high transaction costs of reaching remote areas; the need for localised crop and livestock management solutions suited to tough environmental conditions, which are often not well understood by extension agents trained for work in high potential areas; and the challenges of finding professional extension specialists willing to live and work in remote, and sometimes insecure areas (Coupe, 2009; Rivera, Qamar, and Crowder, 2001).

The community-based rural agricultural extension model is based on the idea of providing specialised and intensive technical training to one or two people in a community who then promote a variety of appropriate technologies and provide technical services with occasional support and review from a supporting organisation (FAO, 1997). This model is demand-based in that the providers of service are contracted directly by farmers’ groups or communities to deliver information and related services that are specified by farmers (Feder et al, 2010; Rivera, 2001). These models have generally experienced a high degree of success in terms of discovering or identifying productivity enhancing technologies, which are then widely adopted. They have also been able to do so at relatively low cost (Scarborough, 1995).

Description

Farmer-to-farmer systems of extensions are based upon some key principles (Bunch, 1982):

- Motivate farmers to experiment with new technologies on a small scale;
- Use rapid, recognisable success in these experiments to motivate others to innovate
- Use technologies that rely on inexpensive, locally available resources
- Begin with a limited number of technologies to retain focus
- Train villagers as extensionists and support them in teaching other farmers.

In general, there are five stages to implementing the rural extensionist model (De la Torre, 2008).

Stage 1: Creating a Space for Public Debate and Institutional Coordination

As a first step, it is necessary to stimulate debate around the role of rural extension services and technical capacity-building in rural areas. This space should be created between communities and local public and private institutions. These could include state entities working on agricultural/livestock development, producers associations, water user boards, agricultural/livestock research institutes, local universities, private agriculture and/or livestock companies and NGOs.

Stage 2: Establishment of Training Centre

The next step is to establish an appropriate training entity with inter-institutional support. The design should be decentralised and sensitive to the local socio-cultural context. A group of technical experts is required to design and provide the training modules. A budget will be required for their remuneration, for materials and equipment and training activities. Figure 4.18 shows a local training centre for agricultural extension agents in Peru.

Figure 4.18 Farmer Centre in Peru Where Local Agricultural Extension Agents Are Trained



Source: Courtesy of Jon Hellin, *Practical Action* 2003

Stage 3: Training Rural Extension Agents

Training is designed to reflect the livelihoods of the local communities. For example, in Kenyan pastoralist zones, training could concentrate on livestock. In Bangladesh, training could focus on fisheries, agriculture and livestock. Communities elect candidates against a list of agreed criteria and a consensus is reached on the best individual or individuals to be put forward. Training is organised with the participation of relevant district-level government staff, whose fees are paid for from project budgets. Activities include visits to technology development and research centres, the establishment of trial testing and experimentation plots, and problem-solving workshops. Upon completing the training, participants should receive official certification from a state body.

Stage 4: Ongoing Technical Support and Evaluation

Technical experts should be available to provide ongoing support to rural extensionists and also to be responsible for undertaking follow-up impact evaluation via household surveys. This information should be systematised and documented to feed into future programmes.

Stage 5: Knowledge Refresher Courses

Periodic refresher courses should be made available to rural extensionists. These courses should provide a space for participants to feedback on their experiences and contribute to the improvement and refinement of training materials. This can be undertaken at the training centre hub or through visits to the extensionists at work in their respective communities.

How the Technology Contributes to Climate Change Adaptation

The community-based rural extension model contributes to climate change adaptation and risk reduction by building the capacity of communities to identify and select appropriate strategies in response to observed impacts of climate variability on local livelihoods. The model promotes a rural outreach programme that provides assistance to many communities that would otherwise not receive technical support services. As a result of these services, farmers have generally been able to increase crop and livestock production. This, in turn, has positive effects on family health and food security. In addition, rural extensionists have been instrumental in supporting local communities to develop affordable new products for local markets (Coupe, 2009).

Advantages

Rural agricultural extension programmes can help reduce the costs of providing extension services that emanate from the scale and complexity of centralised systems (Feder et al, 2010). Rural extensionists themselves benefit from the accumulation of new knowledge and technical skills and, through this, are able to generate additional income by charging for their services. The strengthening of social and professional networks via this model provides vital access to information and, by working directly with local producers and passing on acquired knowledge, rural extensionists are building the technical capacity of their communities (Feder et al, 2010). They learn, for example, to detect illnesses amongst livestock and implement preventive measures, thereby reducing the need for costly veterinary services. Other benefits include improved self-confidence and innovation on the part of rural extensionists.

Disadvantages

In terms of limitations, the model may face problems where rural farmers do not have the means or are not willing to pay for technical services. In societies where paying for information is not the norm, rural extensionists will have to work hard to earn trust and acceptance as a service provider who is able to charge and make profits within the community from which they originate. Wherever they work, it will take time for extensionists to build up the skills and client base and, providing inputs, establish their position and reputation (Coupe, 2009). The model also depends on adequate technical expertise being available locally, either from civil society, NGOs, governmental or private entities, and the capacity of a local institution to adequately integrate this information into local know-how.

Knowledge and Monitoring Requirements

The training of farmers as community-based extensionists is a complex educational process that needs to be constantly and flexibly adapted to the social and cultural conditions of each locality and the institutional and natural resource context of local agricultural production. Community-based rural extensionists require specialised technical training on locally appropriate agricultural practices including crop, soil and water management, animal husbandry, and fisheries to fill the service vacuum left by the state and formal private sector. The curriculum should be designed to reflect the educational level of the participants. Cultural and

linguistic barriers must also be taken into account in the delivery of the training. Training should promote action-research, farmer-to-farmer learning and learning-by-doing; under a methodology that combines theoretical and practical aspects.

Costs and Financial Requirements

External financing will usually be required to set up training schools for agricultural extension. When the training is carried out by local organisations and farmer facilitators, initial start-up costs may be moderate, but the running costs will be much lower. In Peru, between 1996 and 2000 the average annual cost of training a rural agricultural extensionist was \$ 1,200 (De la Torre Postigo, 2004). Estimates of costs per farmer for Farmer Field School (FFS) training in several East African programmes vary between US\$ 9-35 per day, depending on whether extension agent or farmer facilitators are used (Dragun, 2001). It may be possible to charge extensionists a small fee for training, depending on an assessment of their capability to do so. In East Africa, extensionists have been managing small commercial plots alongside the study plots in order to raise funds to buy inputs and stationery (Braun and Duveskog, 2008). In Bangladesh, training by Practical Action and department officers in 2002-3 including equipment donation, refresher training and field follow-up came to 12,730 Taka per person (\$ 177) in the case of livestock and 8,050 Taka per person (\$ 112) in the case of agriculture and fisheries (Coupe and Pasteur, 2009).

Institution and Organisational Requirements

It is necessary to promote debate on the importance of extension and rural technical education by means of coordinated efforts with all the institutions present in the zone that are dedicated to rural development. These are likely to be state institutions dedicated to agricultural development, associations of producers, organisations of water users, research institutes, local universities, private companies and NGOs.

It is desirable to obtain an inter-institutional agreement between a group of institutions to push forward the development of a system of extension that responds to the particular needs of the locality. Identifying the best farming practices in the intervention area, be they from individual farmers, producer associations or companies, and securing support for training of the community-based extensionists can also generate important financial and technical support.

Establishment of a training institute with the support of the group of institutions identified will help to ensure long-term sustainability. Finally, there is a need to create a model for institutionalising rural extension training within a broader framework for formal training and education institutions in order to facilitate scaling-up.

Barriers to Implementation

Barriers to implementation include a lack of appreciation for local knowledge. This can be overcome with concerted action to validate and disseminate information on indigenous practices and develop appropriate technologies that combine this know-how with modern strategies. A lack of access to credit by extensionists to buy basic equipment required for technical service provision can also act as a barrier to successful implementation.

Opportunities for Implementation

The implementation of the rural extension model provides an opportunity for the generation of innovative sustainable agriculture and livestock development strategies which embrace local customs and know-

how. Furthermore, the model facilitates the development of entrepreneurial skills amongst participants and provides multiple co-benefits that reach far beyond the immediate impacts on the extensionists themselves. Another opportunity provided by this model is the establishment of strategic alliances between local educational, technological and scientific entities to promote the exchange of information and facilitate wider dissemination and uptake.

A Real Example of Application

Box 4.51 Rural Extensionist Experiences from Bangladesh and Kenya

In the Turkana region of northern Kenya, animal health is critical to the livelihoods of pastoralist communities. However, formal veterinary services often do not reach the remote areas where many pastoralists live.

Community-based Animal Health Workers (CBAHWs) have been recognised as having a role in bridging this gap for more than a decade under national policy in Kenya, but in reality there has been little penetration of CBAHWs into mainstream veterinary practices. Practical Action Eastern Africa has been working to change this. It has encouraged the Turkana District Veterinary Office to train more CBAHWs and to provide monitoring and a referral service for complex cases. Practical Action Eastern Africa has also been instrumental in making links between the CBAHWs and private sector drug and vaccine suppliers (Coopers K Brand and Norbrook), ensuring product use training and a reliable supply chain for critical medicines.

CBAHWs are now seen to provide a surveillance role on behalf of the District Veterinary Office as primary disease monitors. They are also seen to be responding to calls for assistance within 24 hours and kraal-level reports indicate survival rates of treated livestock identified as at-risk by CBAHWs have reached 70 per cent, compared to a 15 per cent baseline. On average, 2 drug transactions per month were sourced by CBAHWs from private sector suppliers. None existed before this work. Eldoret's Norbrook sales manager, Dr. Were, has identified Ksh70,000 worth of new transactions every month through this channel: "I never ever expected anything of this kind to come from pastoralists. It is a business opportunity we need to refocus on."

Source: Practical Action website, www.practicalaction.org

4.7.2 Farmer Field Schools

Definition

The Farmer Field School is a group-based learning process that has been used by a number of governments, NGOs and international agencies originally to promote integrated pest management (IPM). The first FFS were designed and managed by the Food and Agriculture Organisation (FAO) in Indonesia in 1989. They were developed in response to perception that small farmers were not managing agrochemical-based agriculture well, particularly pest management through the use of pesticides. Many farmers did not have the resources to use pesticides, and sometimes wrong uses and storage caused the problems of poisoning. Furthermore many pests seemed to rapidly develop resistance to the pesticides. FFSs bring together concepts and methods from agroecology, experimental education and community development, as a group-based learning process. Overall, FFSs look to reinforce the understanding of farmers about the ecological processes that affect the production of their crops and animals, through conducting field learning

exercises such as field observations, simple experiments and group analysis. The knowledge gained from these activities enables participants to make their own locally-specific decisions about crop management practices. Although FFSs were initiated as a training process for pest control in field crops, the principles have now been adapted to all agricultural production systems from livestock to coffee production.

How the Technology Contributes to Climate Change Adaptation

The FFS approach represents a radical departure from earlier agricultural extension programmes, in which farmers were expected to adopt generalised recommendations that had been formulated by specialists from outside the community. The basic features of a typical rice IPM Farmer Field School are as follows (from Pontius et al, 2002; Bijlmakers, 2005):

- The IPM FFS is field-based and lasts for a full cropping season
- A FFS meets once a week with a total number of meetings that might range from at least 10 (up to 16) meetings
- The primary learning material at a FFS is the cropping field
- The FFS meeting place is close to the learning plots, often in a farmer's home and sometimes beneath a tree
- FFS educational methods are experiential, participatory, and learner centred
- Each FFS meeting includes at least three activities: the agro-ecosystem analysis, a 'special topic', and a group dynamics activity
- In every FFS, participants conduct a study comparing plots with different managements
- An FFS often includes several additional field studies depending on local field problems
- Between 25 and 30 farmers participate in an FFS. Participants learn together in small groups of five to maximise participation
- All FFSs include a 'field day' in which farmers make presentations the results of their studies
- A pre- and post-test is conducted as part of every FFS for diagnostic purposes and for determining follow-up activities
- The facilitators of FFSs undergo intensive season-long residential training to prepare them for organising and conducting FFS
- Preparation meetings precede an FFS to determine needs, recruit participants, and develop a learning contract
- Final meetings of the FFS often include planning for follow-up activities.

The curriculum of the FFS was built on the assumption that farmers could only implement integrated crop management once they had acquired the ability to carry out their own analysis, make their own decisions and organise their own activities. The process of empowerment, rather than the adoption of specific management techniques, is what produces many of the developmental benefits of the FFS.

Climate change brings many complex and unpredictable changes that affect the viability and management of farming systems. Not only are there trends in the change of temperature and rainfall, but also increased climate variability especially in the duration and intensity of the seasons. This affects a whole range of conditions relating to the performance and management of different farming systems, from planting time, to flowering, to the prevalence of different pests and diseases. To cope with this increased variability

farmers will need a greater understanding of the processes that affect the performance of the different production systems they manage and undergo constant experimentation and adaptation of these production systems. More so even than the agronomic knowledge that farmers acquire from participating in farmer field schools, the habits and abilities of constant adaptation are essential for farmers to be able to cope with climate change.

Advantages

Farmer field schools represent an effective mechanism for group training that can reach thousands of small-scale farmers with knowledge and technical content that each can adapt to their own unique circumstances. Beyond this, as has been indicated, these processes empower farmers, both individually and collectively, to more effectively participate in the processes of agricultural development.

Disadvantages

Educating farmers through FFS requires more time from both farmers and extensionists than simple technology transfer or technical recommendations. The experimentation conducted may initially generate more failures than successes, but so too have technical recommendations in the contexts of small farmer agriculture. In the medium term farmers participating in FFS leads to more sustainable impacts.

Knowledge and Monitoring Requirements

Fundamental to the success of FFS is the training of the trainers or facilitators of the FFS. This often requires re-training of extension personnel in a range of skills and attitudes that were not part of their initial training. Extension personnel have typically been trained in technology transfer rather than adult education and participatory learning. FFS require facilitators to have abilities in developing understanding of the participants of agroecological processes, but not through 'lecturing' on these processes, but through facilitating the farmers in discovery exercises to find out and understand these processes. Subsequently management options are defined through the integration of local knowledge of the farmers and ecological knowledge gained through the FFS.

Costs and Organisational Requirements

The development of the FFS was through a national IPM programme in Indonesia, which ran between 1989 and 2000, funded by the United States (US\$ 25 million grant), World Bank (US\$ 37 million loan) and the Indonesia government (US\$ 14 million). FAO provided technical assistance to the National IPM Programme through a team of experts based in Indonesia, and on a smaller scale in Bangladesh, Cambodia, China and Nepal. In total, during the 15-year period between 1989 and 2004, approximately US\$100 million in grants were allocated to IPM projects in Asia that used the FFS approach under the guidance of FAO. As a result, more than two million farmers across Asia have participated in this type of learning (Bartlett, 2005).

The cost of conducting a season-long field school for 25 farmers has ranged from \$150 to \$1,000 depending on the country and the organisation. In some cases, the graduates of FFS have saved \$40 per hectare per season by eliminating pesticides without any loss of yield. In other cases, graduates did not experience any savings because they were not previously using any pesticides. However, their yields increased by as much as 25 per cent as a result of adopting other practices learnt during the FFS, such as improved varieties, better water management and enhanced plant nutrition.

The conceptual and methodological problems associated with assessing the impact of IPM field schools have resulted in disagreements among experts about the advantages of this intervention. One widely circulated paper written by World Bank economists has questioned the benefit of 'sending farmers back to school' (Feder, Murgai and Quizon, 2004a and 2004b). By contrast, a meta-analysis of 25 impact studies commissioned by FAO (van den Berg, 2004) concluded that in the majority of studies there were substantial reductions in pesticide use and in a number of cases of increased yield due to training. Furthermore the 'empowerment' impacts of the training resulted in widespread and lasting developmental impacts, such as continued learning, increased social and political skills to enable improved agro-ecosystem management.

Barriers to Implementation

Farmer field schools require substantial changes to the capacity of agricultural extension services, both in terms of the policies of agricultural development and the abilities of those who execute it. Re-training of agricultural extension services both represents an investment, but also resistance at all levels can be a significant impediment. Also since FFS has become a popular concept, there is the danger that the name is used for any kind of group training, but that does not really follow the concepts of building the learning capacity of the participants.

Opportunities for Implementation

Despite arguments among economists and policy makers, there has been widespread enthusiasm for IPM and FFS among farmers and development practitioners in a number of Asian countries. Participation in FFS has always been voluntary. None of the IPM projects and programmes supported by FAO provided financial incentives to participants. On the contrary, participation in FFS has always involved a considerable cost in terms of time and effort. Despite these costs, two million farmers decided to participate. In most countries, the demand for places in an FFS has been ahead of supply, and drop-out rates have been very low. Furthermore, there are many examples of farmers who decided to train other members of their community and continue working as a group after the training came to an end.

More information on farmer field schools can be found at the following addresses:

Global Farmer Field School Network and Resource Centre: <http://www.farmerfieldschool.info/> and www.share4dev.info/ffsnet/documents/3155.pdf.

Case Studies

Box 4.52 Farmer Field Schools on Sweet Potato Production in East Africa

Farmer field schools (FFS) for sweet potato production and post-harvest management were established by the DFID crop protection programme in 22 communities across Kenya, Uganda and Tanzania with over 500 farmers. The first step was to develop training guide and train the trainers, the course was improved through feedback from the participants. Technically the trainers course cover areas of: sweet potato variety development, agronomy, disease and pest management, experimental design and data collection, facilitation and communication skills, planning and farming as a business, postharvest processing and sweet potato product development. Trainers or facilitators included both extension agents but also farmer facilitators.

Contd...

The changes that farmers introduced created the following results:

- Growing sweet potato varieties with high vitamin A content
- Improved access to planting material at the end of the year
- Increase productivity
- Improved decision-making based on economic evidence
- Selling products made from sweet potato
- Setting up village processing units to market products
- Use of different sweet potato recipes
- On the basis of these results national organisations have expanded the FFS programme to over a thousand farmers. As can be seen the results of the process went much beyond the direct areas of training to include social organisation in the processing and marketing of the products.

Source: Stathers et al, 2006b

Box 4.53 Farmer Field Schools for Pest Management in Cocoa

The Sustainable Tree Crops Programme (STCP) of IITA has adapted the FFS method, typically used on annual crops to work with farmers on pest management of cocoa a long-term perennial crop.

The objectives of FFS are to:

- Provide an environment in which farmers acquire the knowledge and skills to be able to make sound crop management decisions
- Sharpen farmers' abilities to make critical and informed decisions that make their farming activities more profitable and sustainable
- Improve farmers' problem-solving abilities
- Show farmers the benefits of working in groups and encourage group activities
- Empower farmers to become 'experts' on their own farms and to be more confident in solving their own problems.

The FFS curriculum developed by STCP on cocoa integrated crop and pest management covers 8 learning topics:

- Black pod disease
- Mirids
- Farm sanitation and cultural practices
- Soil fertility and fertiliser use
- Making decisions about rehabilitating a cocoa farm
- Cocoa quality
- Child labour sensitisation
- HIV/AIDS sensitisation.

As cocoa is a perennial crop, the period between learning sessions with farmers was every two weeks rather than every week which is more typical, but was extended in duration to 9 to 10 months (as opposed to 3-4 months for most annual crops). Equally, the Agroecosystem Assessments (which score pests and diseases) normally conducted weekly in annual crops were done according to the phenology or development of the disease and the crop i.e. more spaced out over time. Furthermore, as the cycle is long, rather than train facilitators over a whole cycle prior to their working with farmers, the facilitators received an initial methodological training, and then conducted sessions with farmers in parallel with the training they received, so as to not delay by a year the start of farmer training.

Source: http://www.worldcocoafoundation.org/scientific-research/research-library/pdf/FFS_implementation_manual1.pdf

4.7.3 Forest User Groups

Definition

In many countries, forest governance has remained a centralised and top-down process. Policies ignore the role of forests in tribal livelihoods and cultures, violating the overlapping laws protecting the rights of these communities. Premises and procedures for identifying and defining forests are poor, resulting in land use conflicts, unclear boundaries, legal disputes and inappropriate management objectives for lands wrongly classified as 'forest'. Forest User Groups (FUGs) represent one mechanism for decentralising forest management and increasing community-based responsibility and authority. FUGs are based on the three principles of participation, collective action and long-term sustainability. They are formed through democratic processes whereby local residents are elected as community representatives to work as an autonomous body alongside existing government authorities to manage forest resources and to articulate the needs and priorities of local people. FUG members may receive training in resource management and participate in multi-stakeholder forest management mechanisms, develop land-use plans in line with national forest laws and regulations, and undertake forest patrols and awareness-raising with the aim of curbing illegal activities (Ensor, 2009; IDS, 2006).

Description

According to Mohan et al (2003) there are four principal phases to implementing a FUG:

- Baseline information assessment of forest users and introductory community meetings to discuss and define objectives and processes, identification of forest boundaries and local needs and priorities
- Preparation of a forest user group constitution (roles and responsibilities) and a forest management operational plan, in liaison with local government authorities
- Election of Forest User Executive Committee
- Formal authorisation of the elected Committee and FUG by local/district forest office and commencement of operations.

How the Technology Contributes to Climate Change Adaptation

FUGs provide a platform through which communities can directly participate in the identification of local problems, needs and possible solutions to climate change and disaster risk. If local communities have systematically assessed their situation and know clearly what they need to best adapt to climate change

impact, they can then effectively contribute to district level plans. These in turn can inform regional and national adaptation plans and programmes (Regmi et al, 2010). In some contexts, FUGs can also provide an effective vehicle for collective community action on a broader range of development activities. These activities include initiatives for improved education, health, sanitation, rural infrastructure and safe drinking water – all of which build the capacity of a community to adapt to future challenges and opportunities presented by climate change.

Advantages

Where FUGs are recognised by local government authorities, restoration of land and forest rights can provide indigenous communities with vital access to resources to strengthen and diversify livelihood activities thus building their resilience against possible impacts of climate change. Environmental benefits can include increased biodiversity and ecosystem resilience through local species conservation, reforestation schemes and decreased rates of illegal logging. Environmental improvements have also been experienced in cases where common property systems for forests have been introduced, leading to more sustainable use and collection of forest products (IDS, 2006).

Disadvantages

Limitations of FUGs emerge when groups only consist of powerful community members and the poorest and most marginalised members receive the fewest benefits (IDS, 2006). Conflicts can arise where resource use amongst local residents is factionalised and diverse (Eagle, 1992). In communities where there is less tradition of working communally, motivation to participate and to understand the benefits of joint-action can be difficult to stimulate and sustain (Ensor, 2009).

Knowledge and Monitoring Requirements

When setting-up a FUG it is important to understand the dynamics of the local communities and to ensure participation from a representative range of community members. A full forest resource assessment should be carried out, preferably using two methods: a participatory appraisal involving community members cross-referenced with quantitative data logged with GIS technology. This inventory can then be used for monitoring purposes (Richards et al, 1999). Knowledge of livelihood activities, labour inputs, forest products flows (including sources, species, and the timing of sales and expenditure), is vital for understanding the potential benefits of FUGs, for identifying FUG objectives and for making a basic economic calculation of the return from local forest resource management (Richards et al, 1999). Undertaking a financial analysis of a FUG system, in which the benefits and costs to different stakeholders can be calculated, can make equity issues more transparent and can be used as a tool for consultation and negotiation within the FUG. Financial indicators can also be used to ensure ongoing accountability and transparency of the FUG process, thereby empowering poorer members of the FUG. Awareness about forestry policy and procedures is also a fundamental requirement as understanding land rights is essential for formulating appropriate livelihood and conservation strategies. For example, a landless farmer is likely to be more interested in generating an income from cash-crops rather than investing time and effort into practices (such as agro-forestry) that yield benefits over the longer term. Likewise, understanding local markets and the demand for forest products is essential for establishing an effective FUG strategy.

Costs and Financial Requirements

The financing of each of these stages and subsequent activities will depend entirely on the local context and the content of forest management plans. However, it is the responsibility of the authorities to finance the necessary training programmes and technical services to enable villagers to develop skills to successfully operate FUGs (IDS, 2006).

Institutional and Organisational Requirements

A sound understanding of cultural, social and political dynamics is required to accompany this process. FUGs will be easier to implement and more likely to succeed where communal working arrangements already exist. In addition, community members will need to be willing to accept the responsibilities of forest resource management and governments must be willing to allocate management responsibilities to local authorities and villagers (IDS, 2006). FUGs will best function where decentralised forest policy supports assignment of authority or certification to the forest user group to manage local forest resources. Knowledge of existing forest policy, boundaries of authority and local legislation processes will therefore be crucial to facilitate FUG establishment and ensure sustainability.

Where conflicts over forest uses are present, these should be discussed proactively in participatory FUG formation and management phases in order to mitigate future conflicts and ensure adequate representation of diverse community needs and priorities. Regular monitoring of consumption of forest products, resource allocation and distribution, the income of different users, inter-group relations and categorisation of rich and poor community members should be undertaken annually in order that the socioeconomic characteristics of user groups are understood by the Executive Committee. Understanding these characteristics should be used to form the basis of fair and transparent management plans that meet the basic needs of users and prioritise benefit-sharing based on the relative economic status of users (Dahal, 1994).

Barriers to Implementation

A critical barrier to effective implementation of FUGs can occur where issues of forest ownership and management responsibilities are confusing and conflicting. In Nepal, for example, National and Local Government Acts assigned responsibilities for forest management to different bodies which created confusion over final rights of ownership and led to ambiguities in the implementation of FUG activities (Mohan, Shin and Murali, 2003).

Weak skills and capacities of disadvantaged groups and poor representation of marginalised community members may limit equitable benefit distribution. To address these issues, there is a need to build the skills of these groups in areas such as literacy, decision-making, and planning. FUGs should be created on the basis of equitable representation of all community groups, including women.

Opportunities for Implementation

Potential opportunities include:

- **Social:** strengthening of decentralised coordination and governance mechanisms, democratic and transparent decision-making, monitoring and fund management; improved relationships and networks (social capital); political empowerment of communities including rights awareness; strengthened tenure, capacities, welfare and security.

- **Economic:** access to non-timber forest products (NTFPs) and timber for direct household use; income from the sale of NTFPs, agro-forestry yields, timber and environmental service markets; employment in forest management activities; pro-poor benefits of community forest use. A benefit-modelling system (to show who gives and gets what, and who could potentially give and get what, based on wealth-rankings and needs) can be a useful tool. Small enterprise development and marketing will also improve capacity to identify and create new livelihood opportunities. Investment of profits in local infrastructure.
- **Environmental:** maintenance of environmental services (biodiversity, soil health, agricultural productivity, carbon sequestration, air and water quality).

A Real Example of Application

Box 4.54 Livelihoods and Forestry Programme in Nepal

The Livelihoods and Forestry Programme in Nepal supports community groups to manage over 396,000 hectares of forest. Community forestry user groups in Nepal have very systematic practices of adaptation to climate change variability. The community forestry user groups in the Livelihoods and Forestry Programme of the UK Department for International Development (DFID) have undertaken participatory vulnerability assessment to prepare maps of forest resources, identified critical hotspots, prioritised risks and hazards, undertaken stakeholder mapping, implemented adaptation pilot projects and provided training to their members.

Impacts

- Working with community forests that are estimated to sequester about half a million tons of carbon annually. If this carbon becomes tradable it will be worth a substantial amount
- The numerous income generating activities and micro-enterprises that increase poor peoples' wealth and assets help them increase their resilience to effects of climate change
- Conducting studies into impacts of climate change on the forestry sector, community level vulnerability and responses, and ecosystem services
- Piloting practices relating to climate change adaptation
- Helping shape the development of adaptation plans nationally, locally and at FUG level. Providing support to FUG-level planning for climate change
- Expanding the use of alternative renewable energy sources
- Building the capacity of partners and stakeholders, whether increasing awareness of the threats and opportunities of climate change or developing skills for international negotiation.

Challenges

- Demonstrating that FUGs are competent to manage, use and distribute any adaptation funding
- Ensuring the voices of the poor and marginalised are well heard and influence national planning and negotiations
- Developing adaptation plans in time – as effects of climate change are already being felt and the poorest are noticeably most vulnerable.

Source: Livelihoods and Forestry Programme, <http://www.lfp.org.np/>. Accessed in 2011

4.7.4 Water User Associations

Definition

A Water User Association (WUA) is an organisation for water management made up of a group of small and large-scale water users, such as irrigators, who pool their financial, technical, material, and human resources for operation and maintenance of a local water system, such as a river or water basin. The WUA is usually run out of a non-profit structure and membership is typically based on contracts and/or agreements between the members and the WUA (IWMI and SIC ICWC, 2003). WUAs play a key role in integrated approaches to water management that seek to establish a decentralised, participatory, multi-sectoral and multi-disciplinary governance structure.

Description

A WUA is a unit of individuals that have formally and voluntarily associated for the purposes of cooperatively sharing, managing and conserving a common water resource. The objectives of a WUA commonly include:

- Conservation of water catchments
- Sustainable water resource management
- Increase availability of water resources
- Increase the usage of the water for economic and social improvements
- Development of sustainable and responsive institutions.

The core activity of a WUA is to operate the waterworks under its responsibility and to monitor the allocation of water among its members. Key functions of a WUA include:

- Exchange information and ideas on water resource use
- Monitor water availability and use (Box 4.54)
- Provide technical assistance in areas such as soil, water and crop management, livelihood diversification, marketing, finance and savings
- Discuss potential projects and developments (including climate change) that may affect water usage
- Operate and maintain a water service or structure (such as water mill, canal, or irrigation)
- Management of a water distribution system, including setting tariffs and collecting fees
- Resolve conflicts related to water use
- Representation of stakeholder needs at higher institutions of water management.

Box 4.55 Participatory Water Resource Monitoring Pangani Basin Water Management, Tanzania

Pangani is a water-stressed basin (defined as <1,200 m³ of water per person per year) and climate change is expected to greatly exacerbate this condition. Tanzania's Initial National Communication (INC) predicts temperature rises, rainfall decreases, and evaporation increases in the Pangani Basin, which together are expected to result in a 6 to 10 per cent decrease in the annual flow. River flows have already declined to the point that seawater intrudes about 20 km upstream from the estuary.

Agriculture is the biggest user of water with over 50,000 hectares of fields irrigated in the Pangani Basin. This includes large commercial estates (coffee and sugar), flower farming and small-scale mixed cropping.

Contd...

Water use efficiency among irrigation systems is very low (often less than 15 per cent). Livestock are also kept throughout the basin, including dairy cattle, goats and sheep. Other goods derived from the basin include aquatic plants, food and medicinal plants and fish, crocodiles, hippos and water birds that are harvested for sale. The supply of all these goods is affected by the quantity and quality of runoff in the catchment. Conflicts are emerging between various water users. As the effects of climate change cumulatively increase, escalated conflicts, environmental degradation, and loss of livelihoods are more likely.

The Pangani River Basin project has promoted a strong decentralisation policy in which WUAs participate through Catchment Forums where water users can discuss and analyse local water management issues, have a voice in the allocation of water and negotiate equitable solutions to water conflicts. Participatory water resource monitoring has been implemented via Environmental Flow Assessments which provide technical information to water managers on the water allocations necessary to maintain environmental goods and services. These technical studies describe the social, economic and environmental implications of various alternative water allocation scenarios in order to find the optimal balance among competing uses.

Source: The Pangani River Basin Management Project

How the Technology Contributes to Climate Change Adaptation

A WUA can contribute to adaptation to climate change by providing a cooperative mechanism through which the following activities can be undertaken:

- Monitor the impact of climate change on water resources
- Empower water users and decision-makers to manage and allocate water resources with consideration for climate change, the environment and other technical information through consultative processes
- Promote basin-level participation in national climate change and water management processes
- Develop and disseminate awareness materials on the implications of climate change and various likely water resource scenarios among local authorities, decision makers, communities and the private sector
- Provide data for modelling possible environmental, economic and social impacts of climate change resulting from changes in water resources
- Prioritise investment needs for water management adaptation strategies, such as irrigation, and monitor their effectiveness.

Advantages

WUAs can play a critical role in changing from centralised control of natural resources to local management. This is particularly important for climate change adaptation efforts whereby local monitoring of water resources, improvements in infrastructure (such as canals and irrigation) and public participation in decision-making leads to more reliable and equitable distribution of supplies. This can lead to improved agricultural productivity, which in turn helps to raise incomes and contributes to local and national food security. An analysis of seven schemes in Nepal found that by supporting livelihood diversification and making improvements to water management infrastructure, WUAs had a direct role in increasing agricultural productivity and income-earning opportunities of farmers (INPIM, 2010). In the province of Mendoza in

Argentina, the organisation of 21 WUAs to administer inspections of a canal that supplies water for 13 985 hectares of agricultural land has led to annual benefits estimated at US\$ 41 000, 2.1 times the annual budget of the inspections (Chambouleyron, 1989). The formation of a WUA can also generate positive impacts for the environment. For example, improvements to canal and irrigation schemes can reduce water logging and salinity problems. By providing technical assistance to local farmers, WUA members can also have a direct impact on improving soil, water and crop management practices (UNESCO, no date).

Disadvantages

The cooperative model of organisation on which the WUA approach is based can have disadvantages if the area of operation does not match a hydraulic boundary and may actually stimulate conflict over resource use (for example, in the Cauvery River in Southern India). Conflicts related to irrigation farming occur between upstream and downstream farmers when the upstream farmers are (perceived as) using too much water. A WUA could heighten conflict between users where its membership is based on an existing community boundary rather than a representative selection of all water users within a particular system.

Knowledge and Monitoring Requirements

Knowledge and monitoring requirements include:

- General business and legal skills required to set-up and maintain the functioning of the WUA as an institution. This will include general awareness-raising amongst members about their roles and rights as well as more targeted training for individual members assigned to carry out specific roles such as bookkeeping, financial reporting, report writing, conflict management and leadership
- Training in water management systems. This can include infrastructure construction and maintenance, such as canal maintenance, pump operation and the monitoring and collection of water use charges
- Training in agricultural production (crop, soil, water and livestock management) depending on the characteristics of local livelihood activities. Training in the provision of outreach services to community members could also be required.

Costs and Financial Arrangements

The cost of establishing and maintaining a WUA will depend on its size, management structure, area of operations and functions. WUAs usually levy a joining fee, and then an annual membership fee. During initial formation phase, additional financial support may be required to ensure the establishment of the WUA. Where the establishment of WUAs is supported by national policy (such as a Water Act or Irrigation Act) there may be a mechanism in place for provision of this funding support. Furthermore, this funding support may be on-going, especially in countries where WUAs are considered part of a government-led decentralisation programme.

International development donors, such as USAID, the EU and the Asian Development Bank, have also provided funding to WUAs. Independently, WUAs can generate income by charging for water supply and distribution services and provision of agricultural outreach services, such as technical assistance for improved crop management or marketing advice. WUAs may also initiate their own commercial activities, such as fish or bee-keeping.

Institutional and Organisational Requirements

WUAs are generally run out of institutions that have previous experience with collective water management, such as irrigation boards. Where an appropriate national framework is in place (usually a Water Act or Irrigation Act), a WUA can become an independent legal entity upon approval of an application to a higher authority such as the Ministry of Water Resources. The WUA is then able to establish a governing document or constitution, a membership and a bank account. A WUA can be established by taking the following main steps:

- Select host institution and register the WUA with the relevant national authority
- Identify stakeholders within the common water resource catchment, raise awareness of the roles and responsibilities of the WUA amongst possible members and recruit
- Identify water management problems via a participatory diagnostic analysis
- Establishment of a business plan and constitution
- Elect an Executive Committee and recruit management staff
- Provide training to members, for example, in planning, budgeting, and civil works construction.

In terms of organisational structure, a WUA tends to comprise:

- A General Assembly, comprised of all WUA members with the main function being to vote on issues of key importance and to elect the Executive Board
- An Executive Board or Council to supervise and provide strategic direction, prepare plans, budgets, submit reports to donors and establish policies
- A manager responsible for day-to-day activities and for making recommendations to the Executive Board
- Operation, maintenance, administrative and financial staff (IWMI and SIC ICWC, 2003; UNESCO, no date).

The WUA will interact with other actors involved in water management such as water catchment authorities, national ministries and the private sector.

It is likely that the activities of a WUA will be relevant to more than one government department, such as the Ministries for Water Resources, Agriculture and Land. The success of the WUA will therefore depend on support from a range of different government actors and will include financial, technical and operational assistance and collaboration.

Legislation ultimately underpins all aspects of WUA formation and activity. It follows that the absence of appropriate legislation will negatively impact WUA sustainability, even if it permits WUAs to be formally established (Hodgson, 2007).

Barriers to Implementation

Experience suggests that if the WUAs are established using a top-down approach, they are weak and have a high risk of failure. WUAs should rather be established through a bottom-up consultative approach working with grassroots level farmers/ water users (IWMI and SIC ICWC, 2003). Other barriers include legal constraints (such as appropriate regulatory frameworks, land and water rights), funding constraints if mobilising funding from year to year becomes a problem, and lack of effective coordination between the

WUA and other relevant authorities and actors. Likewise a lack of capacity in the design and implementation of projects can limit the ability of a WUA to secure funding. In a survey of WUAs in India (UNESCO, no date), members cited funding constraints water availability and government support as the main obstacles to effective WUA implementation.

Opportunities for Implementation

WUAs can offer an opportunity to contribute to the reconstruction of communities through conflict resolution and to involve women in decision-making processes. WUAs also provide a suitable organisational structure through which to support a range of participatory initiatives (such as water resource monitoring) that can help strengthen local capacity to make decisions about natural resource management and agricultural production options in the face of possible climate change scenarios.

A Real Example of Application

Box 4.56 Adapting to Climate Change with Water User Associations in the Great Ruaha River, Tanzania

WWF's programme to restore flows in the Great Ruaha River commenced in 2003, working with communities in eight of 16 districts in the basin, focused on better catchment management and poverty reduction. Local WUAs were established to restore catchments and better manage water by: restoring the source catchments; agreements with major agricultural users to better schedule their water diversions; and enforcement of water laws to shut down illegal diversions. Headwaters and riparian zones were restored by: reducing vinyungu (valley-bottom) farming, removing thirsty, exotic trees; restoring indigenous vegetation, including by reducing felling for charcoal production; protecting riparian zones from grazing; and relocating houses from river banks (80 of 150 have been relocated so far). Agreements with irrigators have reduced transmission losses through coordinated water deliveries, and reduced dry season water use. A 49,000 m³ dam was constructed to secure a water supply for livestock. Each sub-catchment WUA required a month of training and costed US\$13-27,000 to establish. Community Conservation Banks were also established for savings and microcredit. Each of the 20 banks started with a loan of US\$ 4,000 (since repaid) and 30 members, or approximate 150 beneficiaries counting family members.

Adaptation Outcomes

Year-round river flows into the Ihefu wetlands restarted in 2004. Restored flows and stronger local institutions have reduced the vulnerability of local people to water scarcity. The WUAs are represented in river basin governance processes for the implementation of the Tanzanian Government's new water policies.

Source: WWF, 2008

5. Conclusions

Agriculture represents a key sector for providing economic and social development in developing countries. Most of the world's poor people depend on agricultural production as a main source of household income and smallholder agricultural production contributes the largest proportion of world food supply (IAAST, 2009). It is anticipated that climate change will produce negative and positive impacts on agriculture. Increases in average temperatures, for example, could create conditions for improved agricultural production in some regions, whereas elsewhere drought or heavy rainfall will lead to crop failures and spread of animal disease (IPCC WG II, 2007). The extent of these impacts will depend, in a large part, on the ability of producers to respond and adapt to future climate conditions. This requires immediate efforts to build resilience and adaptive capacity in the face of existing vulnerabilities and high levels of uncertainty.

In this context, this guidebook asserts that key strategies for adaptation in the agriculture sector must be based on principles of sustainable development and diversification. Productivity rates must also be improved in order to meet the dual challenge of achieving food security for the world's billion undernourished and generating sufficient food supply to meet increasing global demand. Whereas small-scale farming alone will not be able to accomplish these goals, large-scale commercial farming is all too often based on unsustainable practices that put future production at risk by damaging the very resources on which agriculture relies. In this guidebook, it is proposed that an agro-ecological approach to agricultural production provides a range of technological options that respond directly to these challenges. agroecology utilises both indigenous farming knowledge and selected modern technologies to draw on and replenish natural resources during the agricultural production process. It is adaptable to both small and large scale farming systems, builds long-term resilience and enhances productivity.

This guidebook is designed to help developing countries assess their needs for technology in the agriculture sector. To achieve this, the guidebook showcases a selection of 22 adaptation technologies that have been applied to small and large scale agricultural production. Each of the technologies is defined and described, and the main technological advantages and disadvantages are discussed. Information on the knowledge, monitoring, institutional and organisational requirements is then provided, along with cost data, where available, and the barriers to and opportunities for implementation are discussed. The broad portfolio of case studies presented from across Latin America, Africa, Asia and Eastern Europe demonstrate the applicability and flexibility of agro-ecological options to different agricultural production systems being implemented in diverse cultural, social, environmental and economic contexts today. It is important to note that there is a currently lack of documented evidence regarding the impact of many of the technologies in a climate change context and including analysis of how they contribute to building adaptive capacity and resilience.

The technologies presented in this guidebook demonstrate the importance of selecting appropriate hardware for the local context and also the vital role of building social and institutional capacity. Technological adaptation and innovation has been taking place at the individual and household level over centuries. However, given increases in climate variability and shifts in historical climate patterns, efforts are required to ensure that producers are able to access relevant information and make informed choices about adaptation options through participatory and inclusive processes. Local, regional and national strategies

for climate change adaptation are also required to facilitate wider pilot-testing of technologies and shared lesson-learning, improve access to finance and achieve scaling-up.

It is recommended that local decision-making on adaptation technologies should take place within the community-based adaptation framework. Community-based adaptation creates mechanisms for inclusive governance that engages a range of stakeholders directly with local or district government and national coordinating bodies, and facilitates participatory planning, monitoring and implementation of adaptation activities. This approach not only helps to ensure that adaptation programmes are acceptable, applicable to local conditions and thus more likely to succeed. It also places producers at the very centre of decision-making processes. Given that understanding current vulnerabilities to climate change is an essential starting-point for planning processes, incorporating local knowledge from those at the forefront of agricultural production is essential. Furthermore, community-based adaptation enables funding to be filtered to those individuals, structures, and organisations most suitably placed to identify and carry out the different actions required.

Recommendations

- There is an urgent need for improved climate modelling and forecasting which can provide a basis for informed decision-making and the implementation of adaptation strategies. This should include traditional knowledge
- Information is also required to better understand the behaviour of plants, animals, pests and diseases as they react to climate change
- Potential changes in economic and social systems in the future under different climate scenarios should also be investigated so that the implications of adaptation strategy and planning choices are better understood
- It is important to secure effective flows of information through appropriate dissemination channels. This is vital for building adaptive capacity and decision-making processes
- Improved analysis of adaptation technologies is required to show how they can contribute to building adaptive capacity and resilience in the agriculture sector. This information needs to be compiled and disseminated for a range of stakeholders from local to national level
- Relationships between policy makers, researchers and communities should be built so that technologies and planning processes are developed in partnership, responding to producers' needs and integrating their knowledge.

Endnotes

1. In this case, the World Bank considers only crops, livestock, agro-forestry, and aquaculture. It does not include forestry and commercial capture fisheries
2. Goal 1: Eradicate extreme hunger and poverty, Goal 2: Achieve universal primary education, Goal 3: Promote gender equality, Goals 4, 5, and 6: Reduce child mortality, improve maternal health and combat HIV/AIDS, malaria and other diseases, Goal 7: Ensure environmental sustainability, Goal 8: Develop a global partnership for development
3. <http://www.wmo.int/pages/prog/gcos/index.php?name=AboutGCOS>, consulted March 2011
4. <http://www.wmo.int/pages/prog/gcos/index.php?name=ClimateMonitoringPrinciples>, consulted March 2011
5. Detailed information about crop stages – also known as the “crop calendar” – plays an essential role in crop monitoring and forecasting. This is because the effect of environmental conditions on crops depends very much on crop growth stages. For instance, water requirements are normally low at the initial growth stages, while they reach a maximum just after flowering. (http://www.fao.org/nr/climpag/agromet/inputs_en.asp, consulted March, 2011)
6. <http://www.trust.org/alertnet/news/cameroon-creates-national-climate-change-observatory>. Retrieved 14th March 2011
7. Oxford Dictionary of Geography. A Dictionary of Geography. Copyright © Susan Mayhew 1992, 1997, 2004
8. The following are the officially designated WMO Global Producing Centres (GPCs) of Long Range Forecasts: Bureau of Meteorology (BoM) from Australia, China Meteorological Administration (CMA)/Beijing Climate Centre (BCC), Climate Prediction Centre (CPC) NOAA from USA, European Centre for Medium-Range Weather Forecasts (ECMWF), Japan Meteorological Agency (JMA)/Tokyo Climate Centre (TCC), Korea Meteorological Administration (KMA), Météo-France, Met Office from United Kingdom, Meteorological Service of Canada (MSC), South African Weather Services (SAWS), Hydrometeorological Centre of Russia. WMO has also designated the following Lead Centres: WMO Lead Centre for Long Range Forecast Multi-Model Ensemble (LC-LRFMME) jointly coordinated by KMA and NOAA/NCEP, WMO Lead Centre for Standard Verification System of Long Range Forecasts (LC-SVSLRF) jointly coordinated by BoM and MSC. Other leading centres providing global seasonal forecasts are the Centre for Weather Forecasts and Climate Studies/National Institute for Space Research (CPTEC/INPE) from Brazil, the International Research Institute for Climate and Society (IRI) from USA and APEC (Asia-Pacific Economic Cooperation) Climate Centre (APCC) from the Republic of Korea
9. See <http://www.metoffice.gov.uk/research/modelling-systems/unified-model/climate-models/glosea4>
10. Project of Tufts University and the University of Georgia funded by the Human Dimensions of Global Change Program, National Oceanic and Atmospheric Administration
11. Ms Anelia Gocheva, National Institute of Meteorology and Hydrology, Tzarigradsko Shose 66, 1784 SOFIA, Bulgaria. Mr Peer Hechler (chairman), Deutscher Wetterdienst, P.O. Box 10 04 65, 63004 OFFENBACH, Germany
12. The overall efficiency comprises conveyance efficiency, field canal efficiency and field application efficiency
13. A device to measure the liquid water content of fog
14. Rain or surface water flow that occurs when soil is infiltrated to full capacity
15. [http://www.appropedia.org/The_'A'_frame_\(Practical_Action_Brief\)](http://www.appropedia.org/The_'A'_frame_(Practical_Action_Brief))
16. [http://www.harper-adams.ac.uk/postgraduate/img/uploaded/All%20photos%20from%20camera%20\(January%2006\)%20075.jpg](http://www.harper-adams.ac.uk/postgraduate/img/uploaded/All%20photos%20from%20camera%20(January%2006)%20075.jpg)
17. Use of urea coating agent helps to retard the activity and growth of the bacteria responsible for denitrification
18. Residual, semi-solid material left from industrial wastewater, or sewage treatment processes
19. Nadep composting is a quick method for recycling agricultural wastes and involves the construction of a simple, rectangular brick tank
20. Vermicompost is the product of composting using worms

21. This is based in the competence between different plants species. The idea is to leave the least space possible for the so-called 'bad herbs' (brush) to be established so that they do not compete for the soil nutrients with the crops and they do not become hosts of plagues (insects) or crop diseases (bacteria and fungi)
22. In this Guidebook, soil health is referred to a soil relatively free of fungi, bacteria and insects, with basic nutrients (nitrogen, phosphorus, and potassium) in optimal level and with acidity or alkalinity levels (pH level) that make them available for crops
23. This section is prepared based on IT Publications and UNIFEM 1995
24. <http://www.worldagroforestrycentre.org/research/overview>
25. Extensionists are technically qualified individuals who provide outreach services to rural areas

6. References

Achmadi, U. F. (1991) "Agricultural Injuries in Indonesia: Estimates and Surveys". Department of Public Health Working Paper, University of Indonesia, Jakarta, 1991

Agroasemex (2006) The Mexican Experience in the Development and Operation of Parametric Insurances Applied to Agriculture, Working Paper, August 2006. Available online at: http://www.agroasemex.gob.mx/media/publicaciones/agricola_in.pdf

Alexandrov, V. (2006) Using Better Climate Prediction in the Implementation of National Action Programmes (NAPs) – (Eastern) Europe, Environmental Science and Engineering, pp 537-551, 2007

Alpuerto, V-L, Norton, R.W., Alwang, J. And Ismail, A.M. (2009) Economic impact analysis of marker-assisted breeding for tolerance to salinity and phosphorous deficiency in rice. Review of Agricultural Economics 31(4): 779-792

Altieri, M. A. (2002) Agroecology: the science of natural resource management for poor farmers in marginal environments. Agriculture, Ecosystems and Environment 1971, pp1–24. 2002

Altieri, M. A. (2009) Agroecology, Small Farms, and Food Sovereignty. Monthly Review, July-August 2009

Altieri, M. A. and C. I. Nicholis (2005) Agroecology and the Search for a Truly Sustainable Agriculture, UNEP, Mexico, 2005

Altieri, M. A. and C. I. Nicholls (2009). Cambio climático y agricultura campesina: impactos y respuestas adaptativas. LEISA revista de agroecología, Issue 24, Volume 4, 2009

Altieri, M. A., and P. Koohafkan (2008) Enduring farms: Climate change, smallholders and traditional farming communities, Third World Network, 2008

Altieri, M. A., P. Rosset and L. A. Thrupp (1998) The Potential of Agroecology to Combat Hunger in the Developing World, IFPRI 2020 Brief 55, Washington DC, October 1998

Alvarez, G. S. and L. T. Vilca (2008) Ancestral Bio-Indicators in Andean Highland Regions: Disaster Warning and Resilience Mechanisms, Mountain Forum Bulletin Vol 8 (2) July 2008

Antle, J. M. and P. L. Pingali (1994) "Pesticides, Productivity, and Farmer Health: A Philippine Case Study". American Journal of Agricultural Economics 76 (August 1994): 418-30

Antle, J. M., J. J. Stoorvogel and R. O. Valdivia (2004) Assessing the economic impacts of agricultural carbon sequestration: Terraces and agro-forestry in the Peruvian Andes, Agriculture, Ecosystems & Environment, Vol 122 (4) December 2004, Pp. 435-445

Apigian, J. H. (2005) A Critical Look at the Development of Fog Water Collection in Nepal, Nepal Community Development Foundation (NCDF) and Nepal Water for Health (NEWAH), Kathmandu, Nepal, 2005

Arribas, A., M. Glover, A. Maidens, K. A. Peterson, M. Gordon and C. MacLachlan (2009) Towards a new generation of seasonal forecasting systems. *Física de la Tierra*, 21, 219-224, UK, 2009

Badgley, C., J. Moghtader, E. Quintero, E. Zakem, M. Jahi Chappeli, K. Avilés-Vázquez, A. Samulon, and I. Perfecto (2006) Organic agriculture and the global food supply. *Renewable Agriculture and Food Systems* 22(2): 86-108

Baker P. and J. Haggard (2007) Global Warming: The Impact on Global Coffee. Invited presentation to Specialty Coffee Association of America Symposium, Long Beach, California, May 2007

Bartlett A. (2005) Farmer Field Schools to promote Integrated Pest Management in Asia: the FAO experience, Workshop on Scaling Up Case Studies in Agriculture. IRRI

Belay, T. (2009) Introducing cactus-based agro-forestry practices to the dry lands, Knowledge for Development Dossier on Dryland Agriculture, The Technical Centre for Agricultural and Rural Cooperation (CTA), Netherlands, March 2009

BIAC (Business and Industry Advisory Committee to the OECD) (2009) Agriculture and climate change, Issues for consideration. November 2009, Paris, France

Bijlmakers, H. (2005) Farmer Field Schools for IPM – Refresh your Memory, IPM DANIDA

Boers, T. M. and J. Ben-Asher (1982) "A review of rainwater harvesting". In *Agriculture Water Management*. 5:145-158. 1982

Braun, A. and D. Duveskog (2008) The Farmer FieldSchool Approach – History, Global Assessment and Success Stories, Background paper for the IFAD Rural Poverty Report 2010, October 2008

Brinkman, R. and W.G. Sombroek (1996), The effects of global change on soil conditions in relation to plant growth and food production. In F. and W.G. Sombroek eds. *Global Climate Change and Agricultural Production*. Bazzaz FAO and Wiley, Chichester, UK. p 49-63

Brush, S. B. (1986) Genetic diversity and conservation in traditional farming systems. *J. Ethnobiol.* 6:151-167. 1986

Bunch, R. (1982) *Two Ears of Corn: A guide to people-centred agricultural improvement*, World Neighbors, 1982

CARE 2009 A. Dazé, K. Ambrose and C. Ehrhart, *Climate Vulnerability and Capacity Analysis (CVCA) Handbook*. CARE International, May, 2009

CARE (2010) *Toolkit for Integrating Climate Change Adaptation into Development Projects – Digital Toolkit – Version 1.0* CARE International, with technical input by the International Institute for Sustainable Development (IISD), July 2010

Castiglioni, P., et al. (2008) Bacterial RNA chaperones confer abiotic stress resistance in plants and improved grain yield in maize under water limiting conditions. *Plant Physiology* 147: 446-455

CCTA (2006) Proyecto In Situ. Tecnologías Apropriadas no Tradicionales en la Conservación In Situ de Cultivos Nativos en el Perú, Institución promotora o conocedora: CENTRO IDEAS (Centro de Investigación, Documentación, Educación, Asesoría y Servicios); Grupo TALPUY; Instituto Nacional de Investigación y Extensión Agraria INEIA – EE Santa Ana

Chambouleyron, J. (1989) The reorganisation of Water Users Associations in Mendoza, Argentina, *Irrigation and Drainage Systems* 3: 81-94. 1989

Chang, J. H. (1977) Tropical agriculture: crop diversity and crop yields. *Econ. Geogr.* 53:241-254. 1977

Chapin, F. S., A. L. Lovecraft, E. S. Zavaleta, J. Nelson, M. D. Robards, G. P. Kofinas, S. F. Trainor, G. D. Peterson, H. P. Huntington and R. L. Naylor (2006) Policy strategies to address sustainability of Alaskan boreal forests in response to a directionally changing climate. *Proceedings of the National Academy of Sciences of the United States of America*, 103(45): 16,637-16,643, 2006

Chemonics (2007) Fertiliser Supply and Costs in Africa, Chemonics Inc., July, 2007

Christensen, J. H., B. Hewitson, A. Busuioc, A. Chen, X. Gao, I. Held, R. Jones, R. K. Kolli, W.-T. Kwon, R. Laprise, V. Magaña Rueda, L. Mearns, C. G. Menéndez, J. Räisänen, A. Rinke, A. Sarr and P. Whetton. 'Regional climate projections', in S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds) (2007), *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, pp. 848–940, Cambridge University Press, Cambridge, UK: p854. 2007

Clay, J. (2004) *World Agriculture and the Environment: A Commodity-By-Commodity Guide To Impacts And Practices*, Island Press, March 2004

Commission on Climate Change and Development (2009) *Closing the Gaps: Disaster risk reduction and adaptation to climate change in developing countries*, Ministry for Foreign Affairs, Stockholm, Sweden

CONDESAN (1995), Proyecto PIDAE. La Encañada. Caminos hacia la sostenibilidad. ASPADERUC, CONDESAN – Centro Internacional de la Papa. Fondo Peru – Canada. ISBN 92- 9060177-9. 1995

Cotter, J. and R. Tirado (2009) *Food Security and Climate Change: The answer is biodiversity. A review of scientific publications on climate change adaptation in agriculture*, Greenpeace, June 2008

Coupe, S. (2009) *Impact of Kamayoq (Community-Based Extensionists) in Canchis Province, Cusco Region, Peru*, Internal Evaluation Report, Practical Action, Rugby, UK, 2009

Coupe, S. and K. Pasteur (2009), *Food and Livelihood Security Lesson Learning Study including Community Extension. Bangladesh Country Study Report. Practical Action Project Report*, May 2009

Dahal, D. R. (1994) *A Review of Forest User Groups: Case Studies from Eastern Nepal*, International Centre for Integrated Mountain Development, Kathmandu, Nepal, 1994

Damman, G. (Ed.) (2008) Sistemas de información y alerta temprana para enfrentar al cambio climático: propuesta de adaptación tecnológica en respuesta al cambio climático en Piura, Apurímac y Cajamarca, Soluciones Prácticas-ITDG, Lima, Peru. P.166, 2008

De Dios, H. B. (2002) Participatory Capacities and Vulnerabilities Assessment: Finding the Link Between Disasters and Development. Oxfam Great Britain – Philippines Programme, Quezon City, Philippines. 2002

De la Torre Postigo (2004) C. De la Torre Postigo. Kamayou: Promotores campesinos de innovaciones tecnológicas. Intermediate Technology Development Group, Peru, 2004

De la Torre Postigo (2008) C. De la Torre. Kamayoc: un sistema de extensión agraria para la producción a pequeña escala, Soluciones Prácticas-ITDG, Lima., Peru, 2008

Delgadillo and Delgado (2003), J. Delgadillo P. and F. Delgado B. Evaluación de la implementación de prácticas de conservación de suelos: el caso, LEISA Revista de Agroecología, 2003

Derpsch, R. (2001) Keynote: Frontiers in conservation tillage and advances in conservation practice, in Stott D. E., Mohtar, R. H., and Steinhart G. C (Eds.) Sustaining the global farm. Selected papers from the 10th International Soil Conservation Organisation Meeting held May 24-29, 1999 at Purdue University and the USSA-ARS National Soil Erosion Research Laboratory, 2001

De Schutter, O. (2010) Report submitted by the Special Rapporteur on the right to food to the Human Rights Council, 17 December, 2010

Dixon, J., A. Gulliver and D. Gibbon (2001) Global Farming Systems: Challenges and Priorities to 2030, FAO, Rome, 2001

Dragun, A. K. (2001) "An Ecological Economics Approach to Pesticide Issues and IPM-FFS," Annex B7, in FAO Mid-Term Review of the Global IPM Facility. FAO. Rome. 2001

Dvorak, K. A. (1996) Catalogue of Soil Conservation Practices and Projects in Central America. Internal Report. Tegucigalpa: International Centre for Tropical Agriculture. 1996

Eagle, S. (1992) Experiences with a Heterogeneous Forest User Group in the Far West of Nepal, Rural Development Forestry Network Papers, 13 e-iv, Overseas Development Institute, London, UK, 1992

EC (European Commission) (2010), Mixed crop-livestock farming could help adaptation in Africa, Science for Environment Policy, DG Environment News Alert Service, EC, 18 March 2010

Ehui, S. K., B. T. Kang, and D. S. C. Spencer (1990) Economic analysis of soil erosion effects in alley cropping, no-till and bush fallow systems in south western Nigeria. Agricultural Systems, 34: 349-368. 1990

EMPRESS (2010) Transboundary Animal Diseases Bulletin No 35, FAO Rome, 2010

Ensor, J. (2009), Biodiverse agriculture for a changing climate. Practical Action, Rugby, UK. 2009

- Ensor, J. (forthcoming 2011) *Uncertain futures: adapting development to a changing climate*. Practical Action Publishing, Rugby, UK (forthcoming 2011)
- Ensor, J. and R. Berger (2009a) *Understanding Climate Change Adaptation: Lessons from community-based approaches*, Practical Action Publishing, Rugby, UK, 2009
- Ensor, J. and R. Berger (2009b) *Community-based adaptation and culture in theory and practice in Adapting to Climate Change: Thresholds, Values, Governance*, eds. W. Neil Adger, Irene Lorenzoni and Karen O'Brien. Published by Cambridge University Press. Cambridge University Press 2009
- Ensor, J. and R. Berger (2009c) *Governance for Community Based Adaptation*, Practical Action Discussion Paper, Practical Action, 2009. Available at http://practicalaction.org/climate-change/docs/climate_change/governance-for-community-based-adaptation.pdf
- Environmental Council of Zambia (2009) *Second National Communication under the United Nations Framework Convention on Climate Change*. Lusaka. Republic of Zambia. 2009
- Esilaba, A. O., J. B. Byalebeka, R. J. Delve, J. R. Okalebo, D. Ssenyange, M. Mbalule and H. Ssali (2004) "On farm testing of integrated nutrient management strategies in eastern Uganda". *Agricultural Systems*, 2004
- ETC Group (2009) *Who Owns Nature? Corporate Power and the Final Frontier in the Commodification of Life*. Communiqué Issue 100. 2008
- Fantappiè M. (no date) *Conservation and Reclamation of Volcanic Deteriorated Soils in Ecuadorian Andes*, no date
- FAO (Food and Agriculture Organisation) (no date) *Conservation Agriculture: Matching production with sustainability*, FAO, no date
- FAO (1982) *Mechanised sprinkler irrigation*. FAO Irrigation and Drainage Paper No. 35. Rome. 1982
- FAO (1988) *Irrigation Water Management: Irrigation methods*, FAO. Rome. 1988
- FAO (1991) *Energy for sustainable rural development projects – Vol 1: A reader in Training Materials for agricultural Planning 23/1*, Food and Agriculture Organisation, Rome, 1991
- FAO (1995) *Dimensions of Need – An atlas of food and agriculture*, FAO, Rome. 1995
- FAO (1995a) *Integrated plant nutrition system*. FAO Fertiliser and Plant Nutrition Bulletin No. 12. Rome. 426 pp. 1995
- FAO (1996), *Livestock & the environment: Finding a balance*, FAO, Rome. 1996
- FAO (1996b) *El control de Plagas. Programa Especial sobre Seguridad Alimentaria*. Focus publicación. <http://www.fao.org/FOCUS/S/SpecIPr/spro12-s.htm>

FAO (1997) Improving Agricultural Extension: A reference manual, FAO, Rome, 1997

FAO (1999) Manual on Livestock Disease Surveillance and Information Systems, FAO, Rome; 1999

FAO (2001), Animal Production and Health. FAO. Rome. 2001

FAO (2003) Trade Reforms and Food Security: Conceptualizing the Linkages, Commodities and Trade Division, FAO, Rome, 2003

FAO (2003a) Project on Livestock Industrialisation, Trade and Social-Health-Environment Impacts in Developing Countries; FAO, Rome, 2003

FAO (2006) Breed diversity in dryland ecosystems. Information Document 9, Fourth Session of the Intergovernmental Technical Working Group on Animal Genetic Resources for Food and Agriculture. Rome. 2006

FAO (2007) Adaptation to climate change in agriculture, forestry and fisheries: Perspective, framework and priorities, FAO, Rome, 2007

FAO (2007a) The State of the World's Animal Genetic Resources for Food and Agriculture, edited by B. Rischkowsky & D. Pilling. Rome. 2007

FAO (2008) Scoping agriculture –wetland interactions: Towards a sustainable multiple-response strategy, FAO, Rome, 2008

FAO (2008a) Climate Change Adaptation and Mitigation in the Food and Agriculture Sector, Technical Background Document from the Expert Consultation Held on 5 to 7 March 2008, FAO, Rome, 2008

FAO (2008b) Current world fertiliser trends and outlook to 2011/12, FAO, Rome, 2008

FAO (2009) The State of Food Security in the World: Economic Crises—Impacts and Lessons Learned. Rome, FAO, 2009

FAO (2010) “Climate-Smart” Agriculture – Policies, Practices and Financing for Food Security, Adaptation and Mitigation, FAO, Rome, 2010

Farm Manager Agriver SAC (2011), Drip irrigation system results Report Jan. 2011

Feder, G., R. Murgai, and J. B. Quizon (2004a) “Sending Farmers Back to School: The Impact of Farmer Field Schools in Indonesia”. Review of Agricultural Economics 26, no. 1 (2004a): 45-62

Feder, G., R. Murgai, and J. B. Quizon (2004b) ‘The acquisition and diffusion of knowledge: The case of pest management training in farmer field schools, Indonesia’. Journal of Agricultural Economics 55, no. 2 (2004b): 221-43

Feder, G., J. R. Anderson, R. Birner and K. Deininger (2010) Promises and Realities of Community Based Agricultural Extension, International Food Research Policy Institute, March 2010

- Fraser, E. (2007) Travelling in antique lands: using past famines to develop an adaptability/resilience framework to identify food systems vulnerable to climate change. *Climatic Change* 83: 495-514. 2007
- Frison E. A., C.S. Gold, E. B. Karamura, R. A. Sikora (1998) Mobilizing IPM for sustainable banana production in Africa Proceedings of a workshop on banana IPM held in Nelspruit, South Africa — 23-28 November 1998, INIBAP, 1998
- Fuertes, E. N. and G. Bonfiglio (2008) Impacto del riego por aspersión en el cultivo de pastos en Cajamarca, mediante el proyecto Yachan. This experience is part of a project implemented by Practical Action in the highlands of Peru. Project lasted 4 years with European Union funding
- GHF (Global Humanitarian Forum) (2009) Human Impact Report: Climate Change – The Anatomy of a Silent Crisis. GHF, Geneva, 2009
- Gocheva, A. and P. Heckler (2004) Questionnaire on CLIPS activities in the NMHSs of RA VI Countries (www.wmo.int)
- Gonzales de Olarte, E. and C. Trivelli (1999) Andenes y Desarrollo Rural: Es la recuperación de andenes una via para el desarrollo rural? IEP-CONDESAN. 1999
- Gould, J. E. (1992) “Rainwater Catchment Systems for Household Water Supply” in *Environmental Sanitation Reviews*, No. 32, ENSIC, Asian Institute of Technology, Bangkok. 1992
- Government of India (2007) Integrated Nutrient Management Annual Report 2006-2007. Government of India, Department of Agriculture 2007
- Grewal, J. S. and R. C. Sharma (1978) Advances in soil fertility and fertiliser use. *Fertiliser. News*, 23(9): 38–45. 1978
- Grigg, D. B. (1974) *The Agricultural Systems of the World: an evolutionary approach*. Cambridge University Press, Cambridge. 1974
- Gruhn, P., F. Goletti, M. Yudelman (2000) Integrated nutrient management, soil fertility and sustainable agriculture: current issues and future challenges, IFRPI 2020 Vision Brief, September 2000
- GTZ (1998) Conserving natural resources and enhancing food security by adopting no-tillage. An assessment for the potential for soil-conserving production systems in various agro-ecological zones of Africa, GTZ Eschborn, Tropical Ecology Support Programme, TÖB Publication, 1998
- Guharay F., J. Haggard, and C. Staver (2005) Final report of results and impacts 1998-2004 of regional program on ecologically based participatory implementation of integrated pest management and coffee agroforestry in Nicaragua and Central America to Norwegian Ministry of Foreign Affairs, CATIE, Nicaragua 130 pp
- Guralnick, J. (2002) Biological Indicators as Early Warning of ESNO Events. Regional Disaster Information Centre (CRID), 2002

Haggar J., F. Guharay, and E. de Melo (2004) From IPM implementation to innovation capacity for income generation, food security and natural resource conservation: formulation of prototype approaches for farm households, growers associations, rural communities and their support sectors. Pre-project appraisal and base-line report to Norwegian Ministry of Foreign Affairs, CATIE, Nicaragua, 89 pp

Haggar, J. and G. Soto (2010) Análisis del estado de la caficultora orgánica en Centroamérica. Report to Coordinadora Latinoamericana de Comercio Justo, CATIE, Nicaragua 58 pp

Hahn, M. B., A. M. Riederer, S. O. Foster (2009) The Livelihood Vulnerability Index: A pragmatic approach to assessing risks from climate variability and change—A case study in Mozambique, *Global Environmental Change* 19 (2009) 74–88

Hall, J. (2003) Environment: Aliens plant species invade Southern Africa. *Global Information Network*. June 27: 1-2. 2003

Hambly, H.V. and T. Onweng Angura (eds) (1996) Grassroots Indicators for Desertification: Experience and Perspectives from Eastern and Southern Africa. IDRC, Ottawa, 1996

Harwood, R.R. (1979) Small Farm Development: Understanding and Improving Farming

Systems in the Humid Tropics. Westview Press, Boulder, Colorado

Hatibu, N. and H. Mahoo (1999) Rainwater harvesting technologies for agricultural production: A case for Dodoma, Tanzania, published in: Kaumbutho P G and Simalenga T E (eds). Conservation tillage with animal traction. A resource book of the Animal Traction Network for Eastern and Southern Africa (ATNESA). Harare. Zimbabwe. 173p. 1999

Hodgson, N. (2007) Legislation for sustainable water associations, *FAO Legal Papers Online* No.69, October 2007

Hoffmann, I. (2008) Livestock Genetic Diversity and Climate Change Adaptation. Livestock and Global Change conference proceeding. May 2008, Tunisia

Holland, J. M. (2004) The environmental consequences of adopting conservation tillage in Europe: reviewing the evidence, *Agriculture, Ecosystems and Environment* 103. 1-25. 2004

IAAST (International Assessment of Agricultural Science and Technology) (2008) Summary for Decision Makers of the Global Report, approved by 58 governments in Johannesburg, April 2008, see Key Finding 7; see A. Wezel et al., “A quantitative and qualitative historical analysis of the scientific discipline of agroecology,” *International Journal of Agricultural Sustainability*, 7:1, 2009, pp. 3-18 (showing the rising interest for agroecology in scientific literature)

IAAST (2009) Agriculture at a Crossroads: Global Report, IAASTD, Washington DC, 2009

Ibarra, H. and O. Mahul (2004) Self-Insurance funds as agriculture insurance providers: the case of Fondos in Mexico. World Bank mimeo

- IBSRAM (International Board for Soil Research and Management) (1990) Organic-matter management and tillage in humid and sub-humid Africa. IBSRAM Proceedings No. 10. Bangkok: IBSRAM
- ICRAF (1996) International Centre for Research in Agroforestry, annual report 1996. ICRAF Nairobi, 240 p
- IDRC (International Development Research Centre) (1995) Reading Clouds in Chile, IDRC Reports, Ontario. January 1995
- IDS (Institute of Development Studies) (2006) Forestry, IDS21 Natural Resources Highlights No.2, Sussex, UK. 2006
- IDS (2009) M. Davies, B. Guenther, J. Leavy, T. Mitchell and T. Tanner, Climate Change Adaptation, Disaster Risk Reduction and Social Protection: Complementary Roles in Agriculture and Rural Growth? Institute of Development Studies (IDS) Working Paper 320, Centre for Social Protection and Climate Change and Development Centre, IDS, University of Sussex, Brighton, UK, February 2009
- IFAD (The International Fund for Agricultural Development) (2002) 'The Rural Poor' in World Poverty Report, IFAD, Rome, 2002
- IFPRI (International Food Policy Research Institute) (1995) Biophysical limits to global food production (2020 Vision). Washington, DC. 2 pp. 1995
- IFRC (International Federation of Red Cross and Red Crescent Societies) (2007) How to do a VCA, A practical step-by-step guide for Red Cross Red Crescent staff and volunteers, IFRC, Geneva, 2007
- INCID (Indian National Committee on Irrigation and Drainage) (1998) Sprinkler Irrigation in India. INCID, New Dehli. 1998
- Indonesian IPM Team (1993) The Impact of IPM Training on Farmers' Behaviour: A Summary of Results from the Second Field School Cycle. IPM National Programme Monitoring and Evaluation Team. Jakarta: BAPPENAS, 1993
- Ingram, K.T., M.C. Roncoli, P.H. Kirshen (2002) Opportunities and constraints for farmers of west Africa to use seasonal precipitation forecasts with Burkina Faso as a case study. *Agricultural Systems* 74: 331-349
- INPIM (2010) Demonstrating Enhanced Productivity of Irrigated Agriculture System through Multifunctional Water Users Associations, Mid-Term Report, INPIM Nepal, July 2010
- IPCC (Intergovernmental Panel on Climate Change) (2001) Climate Change 2001: Synthesis Report. A Contribution of Working Groups I, II, and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change [Watson, R.T. and the Core Writing Team (eds.)]. Cambridge University Press, Cambridge, United Kingdom, and New York, NY, USA, 398 pp. 2001
- IPCC WGII (2007) – Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Fourth Assessment Report of the IPCC on Climate Change, Cambridge University Press, Cambridge, UK, 2007. M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson (eds) Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

IT Publications (Intermeditate Technology Publications) and UNIFEM (United Nations Development Fund for Women) (1995) Storage in Food Cycle Technology Source Books, IT Publications, UK, 1995

IWMI (International Water Management Institute) and SIC ICWC (the Scientific Information Centre Interstate Commission for Water Coordination) (2003) How to Establish a Water Users Association, IWMI and SIC ICWC, March 2003

Joshi, P.K., A. K. Jha, S.P. Wani, L Joshi, R. L. Shiyani (2005) Meta analysis to assess impact of watershed programme and people's action. Comprehensive Assessment Research Report 8, International Water Management Institute, Colombo. 2005

Karaba, A, S. Dixit, R. Greco, K.R. Trijatmiko, N. Marsch-Martinez, A. Krishnan, K.N. Nataraja, M. Udayakumar, and A. Pereira (2007) Improvement of water use efficiency in rice by expression of HARDY and Arabidopsis drought and salt tolerance gene. Proceedings of the National Academy of Sciences (USA) 104: 15270-15275

Khan, Z., D. Amudavi and J. Pickett (2008), Push-Pull Technology Transforms Small Farms in Kenya, PAN North America Magazine, Spring 2008

Kirshen, P., K. Ingram, G. Hoogenboom, C. Jost, C. Roncoli, M. Ruth and K. Knee (2003) Lessons Learned for Climate Change Adaptation; Part 1 – Implementation of seasonal climate forecasting in West Africa; Part 2- Impacts from and adaptation to climate change in Metro Boston, USA. Prepared for Insights and Tools for Adaptation: Learning from Climate Variability, 18-20. November 2003, Washington, DC

Kuika, O., F. Reynès, F. Delobelb, and M. Bernardib (2011) FAO-MOSAICC: The FAO Modelling System for Agricultural Impacts of Climate Change to Support Decision-making in Adaptation, Food and Agriculture Organization of the United Nations, Rome, Italy 14-Apr-11, available at: <https://www.gtap.agecon.purdue.edu/resources/download/5306.pdf>

Kulkarni, S.A., F.B. Reinders and F. Ligetvari (2006) Global Scenario of Sprinkler in Micro-Irrigated Areas. Sept 10 – 16 2006, PWTC, Kuala Lumpur 7th International Micro Irrigation Congress

Kundu, D. K., H. U. Neue, R. Singh (1998) Comparative Effects of Flooding and Sprinkler Irrigation on Growth and Mineral Composition of Rice in an Alfisol. Proceedings of the National Seminar on Micro-Irrigation Research in India: Status and Perspective for the 21st Century. Bhubaneswar, July 27-28, 1998

LEISA (2007) Ecological Pest Management, LEISA Magazine, Volume 23, Issue 4

Lightfoot, D.A., R. Mungur, R. Ameziane, S. Nolte, L. Long, K. Bernhard, A. Colter, K. Jones, M.J. Iqbal, E. Varsa, and B. Young (2007) Improved drought tolerance of transgenic maize Zea mays plants that express the glutamate dehydrogenase gene (gdh4) of E.coli. Euphytica 156: 103-116

Ma, X, JC. Xu, Y. Luo, S.P. Aggrawal SP, JT. Li (2009) "Response of hydrological processes to land-cover and climate changes in Kejie watershed, south-west China". Hydrological Processes. Online. DOI: 10.1002/hyp.7233. 2009

- Mahul, O., and J. R. Skees (2007) "Managing Agricultural Risk at the Country Level: The Case of Index-based Livestock Insurance in Mongolia." Policy Research Working Paper WPS 4325, the World Bank, Washington, DC
- Martin, F. W. and S. Sherman (1992). *Agroforestry Principles*. ECHO (Educational Concerns For Hunger Organization), 1992
- Mars, R. (2005) *The Basics of Permaculture*, Chelsea Green Publishing Company, 2005
- Mazoyer, M. (2001) *Protecting small farmers and the rural poor in the context of globalisation*. FAO. Rome. 2001
- McKenzie et al 2008 M. McKenzie Hedger, T. Mitchell, J. Leavy, M. Greeley, A. Downie and L. Horrocks, *Desk Review: Evaluation of Adaptation to Climate Change from a Development Perspective*, IDS, Sussex, UK, 2008
- McInerney, J. P., K.S. Howe and J.A. Schepers (1992) "A framework for the economic analysis of disease in farm livestock." *Preventive Veterinary Medicine*. 12:137-154. 1992
- Meehl, G. A., T. F. Stocker, W. D. Collins, P. Friedlingstein, A. T. Gaye, J. M. Gregory, A. Kitoh, R. Knutti, J. M. Murphy, A. Noda, S. C. B. Raper, I. G. Watterson, A. J. Weaver and Z.-C. Zhao 'Global climate projections', in S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds) (2007) *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, pp. 748–845, Cambridge University Press, Cambridge, UK: p. 749. 2007
- Meinke, H. and R. C. Stone (2005) *Seasonal And Inter-Annual Climate Forecasting: The New Tool For Increasing Preparedness To Climate Variability And Change In Agricultural Planning And Operations*. *Climatic Change* (2005) 70: 221–253, Springer 2005
- Mengech, A. N., K.N. Saxena and H.N.B. Gopalan (eds) (1995) *Integrated Pest Management in the tropics: Current status and future prospects*. UNEP. John Wiley & Sons Ltd. 1995
- Mithoefer, D. and H. Waibel (2003) *Income and labour productivity of collection and use of indigenous fruit tree products in Zimbabwe*. *Agro-forestry Systems* 59, 295–305. 2003
- Mohan, A., N. Shin, and A. Murali (2003) *Decentralisation, Local Institutions and Forest Management in Chitwan District of Nepal*, paper submitted to the XII World Forestry Congress, 2003, Quebec City, Canada
- Moonga, E. and H. Chitambo (2010) *The role of Indigenous Knowledge and Biodiversity in Livestock Disease Management under Climate Change*, paper presented at the 2nd International Conference: Climate, Sustainability and Development in Semi-arid Regions August 16 – 20, 2010, Fortaleza – Ceará, Brazil
- Muchnik, E., C. Morales and G. Vargas (1997) *Desk Study of CGIAR Commitments in Latin America*, Food and Agriculture Organisation, October 1997

Mutegi, J. K., D. N. Mugendi, L. V. Verchot, J. B. Kung'u (2008) Combining napier grass with leguminous shrubs in contour hedgerows controls soil erosion without competing with crops. *Agro-forestry Systems*, DOI 10.1007/s10457-008-9152-3. 2008

Narayanmoorthy, A. (no date) Drip and Sprinkler Irrigation in India: Benefits, Potential and Future Directions. Available:<http://www.iwmi.cgiar.org/Publications/Other/PDF/Paper%2015%20of%20NRLP%20series%201.pdf>

Nelson, D.E. et al (2007) Plant nuclear factor Y (NF-Y) B subunits confer drought tolerance and lead to improved corn yields on water limited acres. *Proceedings of the National Academy of Sciences (USA)* 104: 16400-16455

Neufeldt, H., A. Wilkes, R. J. Zomer, J. Xu, E. Nang'ole, C. Munster, F. Place (2009) Trees on farms: Tackling the triple challenges of mitigation. *World Agro-forestry Centre Policy Brief 07*. World Agro-forestry Centre, Nairobi, Kenya. 2009

Niamir-Fuller, M. (1994) Women Livestock Managers in the Third World: Focus on Technical Issues Related to Gender Roles In Livestock Production, Staff Working Paper 18, Rome, IFAD, December 1994

Ojasti, J. (2001) *Especies exóticas invasoras. Estrategia regional de biodiversidad para los países del trópico andino*. Convenio de Cooperación Técnica ATN/JF-5887-RG CAN-BID. Venezuela.2001

Oka, I. N.(1995) "Integrated Crop Pest Management with Farmer Participation in Indonesia". Working Papers, Food Crop Research Centre, Bogor, 1995

Ortiz, R (2008) Crop genetic engineering under global climate change. *Annals of the Arid Zone* 47(3&4): 1-12

Ortiz, R., M. Iwanaga, M. P. Reynolds, H. Wu, and J. Crouch (2007). Overview on crop genetic engineering for drought prone environments. *Journal of Semi-Arid Tropical Agricultural Research* 4 <http://www.icrisat.org/jornal/SpecialProject/sp3.pdf> (9 Sept 2008)

Oseni, S. and O. Bebe (2008) Climate change, genetics of adaptation and livestock production in low-input systems, paper presented at ICID+18 2nd International Conference: Climate, Sustainability and Development in Semi-arid Regions August 16 – 20, 2010, Fortaleza – Ceará, Brazil and Hoffmann, I. 2008. *Livestock Genetic Diversity and Climate Change Adaptation*. Livestock and Global Change conference proceeding. May 2008, Tunisia

Patt, A. (2008) 'How does using seasonal forecasts build adaptive capacity?' in *Living With Climate Change: Are There Limits To Adaptation?* Conference and Proceedings 7-8 February 2008, pp.62-67, Royal Geographical Society, London

Patt, A., P. Suarez, and U. Hess (2010) How do small-holder farmers understand insurance, and how much do they want it? *Evidence from Africa*, *Global Environmental Change* 20: 153-161

Pesticide Action Network North America (2009) La agroecología aporta un conjunto de soluciones para las crisis y presiones ambientales que enfrenta la agricultura en el siglo. In *Agroecología y Desarrollo*

Sostenible, Conclusiones de la Evaluación Internacional de las Ciencias y Tecnologías Agrícolas para el Desarrollo, dirigida por la ONU

Pimbert, M., (2006) Transforming Knowledge and Ways of Knowing for Food Sovereignty, the International Institute for Environment and Development, London, 2006

Pimentel, D. H., H. Acquay, M. Biltonen, P. Rice, M. Silva, J. Nelson, V. Lipner, S. Giordano, A. Horowitz, and M. D'Amore (1992) "Environmental and Economic Costs of Pesticide Use". *BioScience* 42 (November 1992): 750-60

Pimentel, D., P. Hepperly, J. Hanson, D. Douds, and R. Seidel (2005) Environmental, Energetic, and Economic Comparisons of Organic and Conventional Farming Systems, *Bioscience* Vol. 55 No. 7. 2005

Pontius, J., R. Dilts, , A. Bartlett (2002) Ten Years of IPM Training in Asia – From Farmer Field School to Community IPM, FAO

Practical Action, Rainwater Harvesting Technical Brief, no date

Practical Action (2010) Climate Change Adaptation in Peru: The local experiences, Soluciones Prácticas, Lima, Peru, 2010

Qaim, M., A. Subramanian, and P. Sadashivappa (2010) Socioeconomic impacts of Bt (*Bacillus thuringiensis*) cotton. Chapt 12 In: Zehr U.B Ed. Cotton: Biotechnological Advances. *Biotechnology in Agriculture and Forestry* Vol 65. Series Editor J.M. Widholm. Springer-Verlag Berlin Heidelberg

Raintree, J. B. (1986) An Introduction to Agro-forestry Diagnosis and Design, International Council for Research in Agro-forestry, Kenya, 1986

Red Cross (2010) West and Central Africa: Early Warning/Early Action, Operations Update No.2, 2010

Red Cross/Red Crescent Climate Centre (2005) 2nd International Work Conference on Climate Change and Disaster Risk Reduction. The Hague The Netherlands 21-24 June 2005

Regmi, B. R., A. Morcrette, A. Paudyal, R. Bastakoti and S. Pradhan (2010) Participatory Tools and Techniques for Assessing Climate Change Impacts and Exploring Adaptation Options: A Community Based Tool Kit for Practitioners, Livelihoods and Forestry Programme, Nepal, 2010

Resosudarmo, B. P. (2008) "The economy-wide impact of integrated pest management in Indonesia" In ASEAN Economic Bulletin Issue Dec 1 2008, Singapore, 2008

Richards, M., K. Kanel, M. Maharjan and J. Davies (1999) Towards participatory economic analysis by forest user groups in Nepal, ODI, June 1999

Richards, P. (1985) Indigenous Agricultural Revolution. Westview Press, Boulder. 1985

Rivera, W. M., K. M. Qamar, and L. V. Crowder (2001) Agricultural and rural extension worldwide: Options for institutional reform in developing countries. FAO. Rome. 2001

Rivero, R.M., M. Kojima, A. Gepstein, A., H. Sakakibara, R. Mittler, S. Gepstein and E. Blumwald (2007). Delayed leaf senescence induces extreme drought tolerance in a flowering plant. *Proceedings of the National Academy of Sciences (USA)* 104: 19631-19636

Rosegrant, W. M., C. Ximing, S. A. Cline (2002) *World Water and Food to 2020: Dealing with Scarcity*, International Food Policy Research Institute, Washington, D.C., USA and International Water Management Institute, Colombo, Sri Lanka. 2002

Rosas, J. C. (2001) "Aplicación de metodologías participativas para el mejoramiento genético del frijol en Honduras" in *Agronomía Mesoamericana* 12 (2): 219 -228. 2001. Universidad de Costa Rica, Alajuela

Roy, R. N., A. Finck, G. J. Blair and H. L. S. Tandon (2006) *Plant nutrition for food security*, FAO Rome, 2006

Sakala, I. (1999) Efforts and initiatives for supply of conservation tillage equipment in Zambia in Kaumbutho P G and Simalenga T E (eds), 1999. *Conservation tillage with animal traction. A resource book of the Animal Traction Network for Eastern and Southern Africa (ATNESA)*. Harare. Zimbabwe. 173p

Sapkota, C. (2010) *Agricultural Trade and Climate Change in South Asia*, Trade Insight Vol. 6, No. 3-4, 2010

SARD (Sustainable Agriculture and Rural Development) (2007) Policy Brief 11, 2007

Savva, A. P. and K. Frenken (2002) *Irrigation Manual Planning, Development Monitoring and Evaluation of Irrigated Agriculture with Farmer Participation*. Volume I Modules 1 – 6. Food and Agriculture Organisation of the United Nations (FAO) Sub-Regional Office for East and Southern Africa (SAFR), Harare, 2002

Scarborough, V. (1995) *Farmer-led approaches to Extension*, Papers presented at a Workshop in the Philippines, The Agricultural Research and Extension Network, ODI, July 1995

Schejtman, A. (2010) *Seguridad Alimentaria y Desarrollo Territorial*. Presentation given at the Annual Conference on Rural Territorial Development in Latin America, Bogota, Colombia. Santiago: RIMISP (Latin American Centre for Rural Development). 16-18 March 2010

Schemenauer, R.S., P. Osses, and M. Leibbrand (2004) Fog collection evaluation and operational projects in the Hajja Governorate, Yemen. In: *Proceedings of the 3rd International Conference on Fog, Fog Collection and Dew*, Cape Town, South Africa, 38

Schemenauer, R.S. and P. Cereceda (1994). Fog collection's role in water planning for developing countries. *Natural Resources Forum*, 18, 91-100, United Nations, New York

Schepp K (2010) *How can small-scale coffee and tea producers adapt to climate change – AdapCC Final Report – Results and Lessons Learnt*. GTZ, 2010

Schepp K., K., Linne, and J. Haggar (2010) *Coffee and Climate Change: Training for coffee organizations and extension services*. AdapCC-GTZ / CaféDirect, Eschborn, Germany, 42 pp

- Seckler, D., U. Amarasinghe, D. Molden, R. de Silva, R. Barker (1998) World water demand and supply, 1990 to 2025: Scenarios and issues. Research Report 19. Colombo, Sri Lanka: International Water Management Institute. 1998
- Seckler, D., R. Barker, U. Amarasinghe (1999) Water Scarcity in Twenty-First Century. *International Journal of Water Resources Development*, Vol.15, Nos. 1-2, pp. 29-42. 1999
- Sharma, B. R., K. V. Rao, K. P. R. Vittal, U. Amarasinghe (2008) Converting rain into grain: Opportunities for realising the potential rainfed agriculture in India. *Proceedings National Workshop of National River Linking Project of India*, International Water Management Institute, Colombo (pp. 239-252), 2008
- Sinha, B., R. Singha and D. Choudhury (2007) Ecological pest management for emerging pest problems in LEISA Magazine, Volume 23, Issue 4, December 2007
- Skees J. (2010) State of Knowledge Report — Data Requirements for the Design of Weather Index Insurance. GlobalAgRisk, Inc. Report to Bill and Melinda Gates Foundation
- Smale, M., M.R. Bellon, J.A. Aguirre, I. Manuel Rosas, J. Mendoza, A.M. Solano, R. Martínez, A. Ramírez, J. Berthaud, (2003) "The economic costs and benefits of a participatory project to conserve maize landraces on farms in Oaxaca, Mexico", in *Agricultural Economics* 29 (2003) 265–275
- Smil, V. (2002) Nitrogen and food production: Proteins for human diets. *Ambio*, 31: 126–131. 2002
- Smit, B. and J. Wandel (2006) 'Adaptation, adaptive capacity and vulnerability'. *Global Environmental Change* 16: 282-292, 2006
- Smith, P. (2005) Agriculture and Climate Change: An agenda for negotiation in Copenhagen, IFPRI Focus 16. 2005
- Snyder, R. L. and J. P. Melo-Abreu (2005) Frost protection: fundamentals, practice, and economics – Volume 1. FAO, Rome. 2005
- Soluciones Prácticas-ITDG (2007) Soluciones Prácticas-ITDG, Tecnologías Respondiendo a los Desastres, Soluciones Prácticas-ITDG, Lima, Peru, 2007
- Soluciones Prácticas-ITDG (2010). Manejo integrado de Recursos Naturales en Alta montaña. Soluciones Prácticas, Lima, Peru. 2010
- Soluciones Prácticas (2011). Tecnologías frente a la Variabilidad Climática. Soluciones Prácticas, Lima, Peru. Pending publication in 2011
- Sorrenson, W. J., C. Duarte, and J. López-Portillo, (1998) Economics of non-till compared to conventional cultivation Systems on small farms in Paraguay, policy and investment implications, Report Soil Conservation Project MAG-GTZ, August 1998
- Stathers, T., S. Namanda, R. Kapinga, G. Khisa, R. Mwanga (2006) Promotion of sustainable sweet potato production and post-harvest management through farmer field schools in East Africa p26-27 in Eds Sweetmore A., Kimmins F., Silverside P. *Perspectives on Pests II: Achievements of research under UK*

Department for International Development Crop Protection Programme 2000-2005. Natural Resources International Ltd. Aylesford UK 206 pp

Stavenhagen, R. (1998) 'Cultural rights: a social science perspective', in Niec, H. (ed.) Cultural Rights and Wrongs. Paris: UNESCO, pp. 1–20. 1998

Tanji, K.K. and N. C Kielen,. (2002) FAO Irrigation and Drainage Paper 61: Agricultural Drainage Water Management in Arid and Semi-Arid Areas. FAO, Rome, 2002

Torres J. and A. Gómez (2008). Adaptación al cambio climático: De los fríos y los calores en los Andes. Soluciones Prácticas ITDG. Lima, Peru

Treacy, J. M. (1989) "Agricultural Terraces in Peru's Colca valley: Promises and problems of an ancient technology." Monographic Source: Browder, J.O. (Ed.) Fragile lands of Latin America: Strategies for sustainable development. Imprint: Boulder (USA). Westview Press. 1989. ISBN 0-8133-7705-6. pp. 209-229. 1989

Troccoli, A., M. Harrison, D. L. T. Anderson, S. J. Mason (eds.) (2007) Seasonal Climate: Forecasting and Managing Risk Springer Academic Publishers, Dordrecht / Boston / London. 2007

UNEP (1982) Rain and Storm water Harvesting in Rural Areas, Tycooly International Publishing Ltd., Dublin.1982

UNEP (1997) Sourcebook of Alternative Technologies for Freshwater Augmentation in Some Countries in Asia, UNEP, Unit of Sustainable Development and Environment General Secretariat, Organisation of American States, Washington, D.C., 1997

UNEP (2010) Connecting the Dots Biodiversity, Adaptation, Food Security and Livelihoods, Nairobi, 2010

UNEP-IETC (1998) Sourcebook of Alternative Technologies for Freshwater Augmentation in Some Asian Countries. IETC Technical Publication Series 8b, UNEP IETC/UNEP-IETC/Danish Hydraulic Institute

UNEP and SEI (Stockholm Environment Institute) (2009) Rainwater harvesting: a lifeline for human wellbeing, United Nations Environment Programme and Stockholm Environment Institute in 2009

UNESCO, Water Users Association for Sustainable Water Management: Experiences from the irrigation sector in Tamil Nadu, India, UNESCO, no date

UNESCO-ROSTLAC (1997) Agua Vida y Desarrollo: Manual de Uso y conservación del Agua en zonas rurales de America Latina y el Caribe. Tomo 3, Técnicas. Proyecto D4-PRM. 1997

UNFCCC (United Nations Framework Convention on Climate Change) (2002), Report of the Conference of the Parties on its Seventh Session, held at Marrakesh from 29 October to 10 December 2001 Addendum Part Two: Action taken by the Conference of the Parties. UNFCCC, 21 January 2002

UNFCCC (2008) Nacional Adaptation Programmes of Action, Summary of Projects on Water Resources identified in submitted NAPAs as of September 2008, United Nations 2008

UNFCCC (2008a) National Adaptation Programmes of Action, Summary of Projects on Territorial Ecosystems identified in submitted NAPAs as of September 2008, United Nations 2008

UNFCCC (2009) Approaches to and experiences in integrating and expanding adaptation planning and action at national, subnational, community and local levels, and lessons learned, good practices, gaps, needs, and barriers and constraints to adaptation SBSTA 13th Session, Bonn 1-10 June 2009. Available at <http://unfccc.int/resource/docs/2009/sbsta/eng/misc04.pdf>

UNISA (University of South Africa) (2008) Research Report, UNISA. Cape Town. 2008

Valdivia, R. O. (2002) The Economics of Terraces in the Peruvian Andes: AN application of sensitivity analysis in an integrated assessment model. Montana State University, Bozeman, Montana, April 2002

Van Aalst, M. K., T. Cannon and I. Burton (2007) Community Level adaptation to climate change: The potential role of participatory community risk assessment. In *Global Environmental Change* 18 (2008) 165–179. Elsevier

Van den Berg. H (2004) IPM Farmer Field School: a synthesis of 25 Impact Evaluations, Wageningen University

Varshney, R.K., K.C. Bansal, P.K. Aggarwal, S. Datta and P.Q. Craufurd (2011) Agricultural biotechnology for crop improvement in a variable climate: hope or hype? *Trends in Plant Science* 16(7): 363-371

Venton, P. and S. La Trobe (2008) Linking Climate Change Adaptation and Disaster Risk Reduction. Tearfund, Trobe. Teddington, United Kingdom, 2008

Vermeulen, M. (2010) Small-scale Farming, LEISA Blog, November 25, 2010. Accessed 8th March http://familyfarming.typepad.com/leisas_farm/small_scale_farming/

Wambugu, P. W., P. W. Mathenge, E. O. Auma and H. A . van Rheenen (2009) Efficacy of Traditional Maize (*Zea Mays* L.) Seed Storage Methods in Western Kenya, in *African Journal of Food Agriculture, Nutrition and Development*, Volume 9 No. 4, June 2009, Nairobi, Kenya, 2009

WaterAid, Technical Brief: Rainwater Harvesting, no date

Wobeser, G. (2002) Scientific and Technical Review of the Office International des Epizooties 21(1), 159-178. 2002

World Bank (2000) Implementation completion report Brazil: Land management II – Santa Catarina project: implementation completion report (Loan 3160-BR). Report #20482, Washington, DC, World Bank. 2000

World Bank (2008) World Development Report 2008 Agriculture for Development, Washington DC 2008

WRI (World Resources Institute) (2005) Millennium Ecosystem Assessment 2005 – Ecosystems and Human Wellbeing: Synthesis, Island Press, Washington, DC. 2005

WWF (Worldwide Fund for Nature) (2008) Water for life: Lessons for climate change adaptation from better management of rivers for people and nature, WWF, UK, August 2008

Yanggen, D., J. M. Antleb and R. O. Valdivia (2003) Análisis Económico de los Subsidios y la Adopción Sostenible de las Tecnologías de Conservación Agrícola: Un Marco Conceptual y un Estudio de Caso de las Terrazas en los Andes de Perú, Montana State University and the International Potato Centre, June 2003

Young (1997) Agroforestry for Soil Management. 2nd Edition. CABI/ICRAF Wallingford UK, 320p

Ziervogel (2001) Global science, local problems: Seasonal climate forecast use in a Basotho village, southern Africa, Gina Ziervogel, Environmental Change Institute. Paper prepared for presentation at the Open Meeting of the Global Environmental Change Research Community, Rio de Janeiro, October 6-8, 2001

Zullo Jr, J., H. Silveira Pinto and D. Assad (2006) Impact assessment study of climate change on agricultural zoning, Meteorological Applications, Supplement: Weather, Climate and Farmers, Volume 13, Issue S1, pages 69–80 , December 2006

Webpages

Adaptation Learning Mechanism, <http://www.dev.adaptationlearning.net/experience/alm-case-study-2010-zimbabwe-coping-drought-and-climate-change> Accessed 2011

Community Development Library, <http://www.greenstone.org/greenstone3/nzdl;jsessionid=55A2D8C024FD2B078DFAC6EABEB49762?a=d&d=HASHb56d01ced7d6c0ecb3b0be.7.pp&c=cdl&sib=1&dt=&ec=&et=&p.a=b&p.s=ClassifierBrowse&p.sa=>, accessed in December 2010

Eldis Community Based Adaption Exchange <http://www.eldis.org/index.cfm?objectid=63551B3B-FDA9-0941-1EAC7111660B5FC5>

FADR (The Foundation for Agrarian Development Research, Russia) <http://www.fadr.msu.ru/rodale/agsieve/txt/vol2/7/art4.html>, accessed in December 2010

FAO website www.fao.org/nr/climpag, accessed in 2011

Fogquest, <http://www.fogquest.org> accessed 2011

Grupo de Meteorología de Santander 2010, <http://www.meteo.unican.es/es/research/prediccion-estacional>, accessed in December 2010

International Potato Centre (2010) http://www.cipotato.org/pressroom/facts_figures/2008_international_year_of_the_potato.asp#2, accessed in 2010

IRRI (International Rice Research Institute) (2010), IRRI Annual Report 2009, published in 2010. available at <http://irri.org/about-irri/annual-reports/annual-report-2009>

Kenya Meteorological Department (2011) <http://www.meteo.go.ke/cmp/index.html>, accessed 2011

Livelihoods and Forestry Programme (2011) <http://www.lfp.org.np/>. Accessed in 2011

Practical Action, <http://practicalaction.org/practicalanswers/index.php?cPath=87> <http://practicalaction.org/east-africa/animal-health-turkana>,

Practical Action, <http://practicalaction.org/food-production/agriculture-community-based-extension>

Practical Action (2009) From Vulnerability to Resilience Framework and Integrating Approaches seminar (contact Hilary Warburton, Aim 1 UK). <http://www.practicalaction.org.uk/reducing-vulnerability/integrating-approaches-seminar>

Prevention web, <http://www.preventionweb.net/english/>

Provention, <http://www.proventionconsortium.org/?pageid=39>, and http://www.proventionconsortium.org/CRA_toolkit.htm, accessed in 2011

Red Cross / Red Crescent Climate Centre, <http://www.climatecentre.org/>

The Pangani River Basin Management Project, www.panganibasin.com

UN International Strategy for Disaster Reduction, <http://www.unisdr.org/>, accessed in 2011

Washtech, <http://washtech.wordpress.com/>, accessed in 2011

WMO (World Meteorological Organisation) (2010) www.wmo.int (accessed in December 2010)

Ziervogel, G. (2007) Wiki Adapt. Accessed in November 2011

Interviews

Medina 2010, Personal interview in December 2010 with Tulio Medina, agronomist from the Instituto Nacional de Innovación Agraria (INIA), Lima, Perú

Torres 2010, Personal interview on December 2010 with Fidel Torres, biologist and potato expert, from the Central Peruana de Servicios (CEPESER), Lima, Perú

Appendix I: Glossary

Abiotic agent: physical factor such as climate, water and soil

Agro-forestry: production system that combines the growing of trees and agricultural / horticultural crops on the same piece of land

Basin: a broadly circular valley or natural depression on the earth's surface

Biotic agent: biological factor such as flora, fauna and microorganisms

Biotic environmental pressures: biological factors, such as pests or diseases, which, for example, attack crops or seeds

Climatic environmental pressures: atmospheric meteorological factors in the environment, such as frost, drought, hail or flood, that, for example, threaten the survival of crops or seeds

Colloidal minerals: These are sometimes mineral compounds: others are elemental in nature. Colloidal minerals keep their own identity and are suspended in water. The molecules tend to group together into clusters. Some colloidal minerals are quite large when compared to the size of cells in the body (source: www.icalcium.com/dictionary.html)

Cultivar: a plant variety that has been produced in cultivation by selective breeding

Dendrology: branch of botany that deals with the study of trees and shrubs

Ethno-botany: scientific study of the relationships that exist between people (cultures) and (use of) plants

Forage: plant material eaten by grazing livestock, often pasture, crop residue and grasses

Forestry: activity that relates to managing forests, tree plantations and related natural resources

Fractioned fertilisation: cause (an egg, female animal, or plant) to develop a progeny by introducing male reproductive material gradually

Hydric soil: soil that forms under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the parts closer to the surface of the soil

Infiltration ditch: a narrow, steep sided, open channel within which storm water is stored and/or filtered into adjacent soil as part of a planned method of disposal

Jhum (or Jhoom): is a local name for slash and burn agriculture practiced by tribal groups in the north eastern states of India and districts of Bangladesh. This system involves clearing a piece of land by setting fire or clear felling and using the area for growing crops of agricultural importance such as upland rice, vegetables or fruits. After a few cycles, the land loses fertility and a new area is chosen

Legume: a plant in the family Fabaceae, a legume is a simply dry fruit. Common examples include peas, beans, lentils, soy and peanuts

Limnimetric scale: hydrometric station with a measuring instrument called a limnimeter (scale or watch) which records the level of the river around a fixed reference

Meristem tissue: Meristem is a type of embryonic tissue in plants consisting of youthful cells called meristematic cells and found in areas of the plant where growth is or will take place, namely in roots and shoots

Parasitoids: are organisms that spend a significant portion of its life history attached to or within a single host organism, which it ultimately kills (and often consumes) in the process (source: www.wikipedia.org)

Phenological cycle: Cycle of changes in the relation between the climatic factors and the living beings

Polinisation: process of fertilisation by pollen grains

Progeny: a genetic descendent or offspring

Root nodule: association between roots of plants and bacteria

Run-off: water flowing over the surface of the ground

Seedling: small plant

Soil inoculants: bacteria or fungi that are added to soils in order to improve plant growth

Ware potato: potato grown for human consumption as fresh or processed product

Watershed: an area or ridge of land that separates waters flowing to different rivers, basins, or seas

Measurements

tn	tons
ha	hectare
m	metres
cm	centimetres
mm	milimetres

Appendix II – Recommended Sources for Additional Information

Altieri, M. A. and C. I. Nicholis (2005) *Agroecology and the Search for a Truly Sustainable Agriculture*. UNEP, Mexico, 2005

Arribas, A., M. Glover, A. Maidens, K. A. Peterson, M. Gordon and C. MacLachlan (2009) Towards a new generation of seasonal forecasting systems. *Física de la Tierra*, 21, 219-224, UK, 2009

Bapna, M., H. McGray, G. Mock and L. Withey (2009) Enabling adaptation; priorities for supporting the rural poor in a changing climate. World Resources Institute (WRI) Issue Brief, Washington DC, 2009

Brooks, N. (2003) *Vulnerability, Risk and Adaptation: A Conceptual Framework*, Tyndall Centre for Climate Change Research, Working Paper 38, Norwich, UK, 2003

Business and Industry Advisory Committee to the OECD (2009) *Agriculture and climate change, Issues for consideration*. OECD, Paris, France, 2009

CARE International, with technical input by the International Institute for Sustainable Development (IISD) (2010), *Toolkit for Integrating Climate Change Adaptation into Development Projects – Digital Toolkit – Version 1.0* CARE, 2010

Cotter, J. and R. Tirado (2008) *Food Security and Climate Change: The answer is biodiversity. A review of scientific publications on climate change adaptation in agriculture*. Greenpeace, 2008

Dazé, A., K. Ambrose and C. Ehrhart (2009) *Climate Vulnerability and Capacity Analysis (CVCA) Handbook*. CARE International, 2009

Davies, M., B. Guenther, J. Leavy, T. Mitchell and T. Tanner (2009) *Climate Change Adaptation, Disaster Risk Reduction and Social Protection: Complementary Roles in Agriculture and Rural Growth?* Institute of Development Studies (IDS) Working Paper 320, Centre for Social Protection and Climate Change and Development Centre, IDS, University of Sussex, Brighton, UK, 2009

Delgado C. L. and A. Siamwalla (2009) Rural economy and farm income diversification in developing countries. pp. 126- 143. In *Food security, diversification and resource management: refocusing the role of agriculture* (eds. G.H. Peters and Joachim Von Braun). Proceedings of twenty-third International Conference of Agricultural Economists. Ashgate Publishing Company, Brookfield, Vermont, USA, 2009

Ensor J. and R. Berger (2009) *Understanding Climate Change Adaptation: Lessons from community-based approaches*. Practical Action Publishing, Rugby, UK, 2009

FAO (Food and Agriculture Organisation of the United Nations), 2007, *Adaptation to climate change in agriculture, forestry and fisheries: Perspective, framework and priorities*. FAO, Rome, 2007

FAO (2008), *Climate Change Adaptation and Mitigation in the Food and Agriculture Sector, Technical Background Document from the Expert Consultation Held on 5 to 7 March 2008*. FAO, Rome, 2008

FAO (2008) *Current world fertilizer trends and outlook to 2011/12*. FAO, Rome, 2008

FAO (2010), “Climate-Smart” Agriculture – Policies, Practices and Financing for Food Security, Adaptation and Mitigation. FAO, Rome, 2010

Meinke, H. and R. C. Stone (2005) Seasonal And Inter-Annual Climate Forecasting: The New Tool For Increasing Preparedness To Climate Variability And Change In Agricultural Planning And Operations. *Climatic Change* (2005) 70: 221–253, Springer, 2005

Reij, C. and A. Waters-Bayer (eds) (2001) Farmer innovation in Africa: a source of inspiration for agricultural development. Earthscan Publications Ltd, UK, 2001

Schepp K., K. Linne, and J. Haggard (2010) Coffee and Climate Change: Training for coffee organizations and extension services. AdapCC-GTZ / CaféDirect, Eschborn, Germany, 42 pp

Sivakumar, M. and N. Ndiang’ui (Eds.) (2007) Climate and land degradation. United Nations Convention to Combat Desertification (UNCCD), Springer, Berlin, 2007

Skees, J. (2010) State of Knowledge Report — Data Requirements for the Design of Weather Index Insurance. GlobalAgRisk, Inc. Report to Bill and Melinda Gates Foundation

United Nations Environment Programme (UNEP) (2010) Connecting the Dots: Biodiversity, Adaptation, Food Security and Livelihoods. UNEP, Nairobi, 2010

United Nations Environment Programme and Stockholm Environment Institute (2009) Rainwater harvesting: a lifeline for human well-being. UNEP and SEI, 2009

United Nations Framework Convention on Climate Change (2009) Approaches to and experiences in integrating and expanding adaptation planning and action at national, subnational, community and local levels, and lessons learned, good practices, gaps, needs, and barriers and constraints to adaptation SBSTA 13th Session, Bonn 1-10 June 2009. Available at <http://unfccc.int/resource/docs/2009/sbsta/eng/misc04.pdf>

Varshney, R.K., K.C. Bansal, P.K. Aggarwal, S. Datta, and P.Q. Craufurd (2011) Agricultural biotechnology for crop improvement in a variable climate: hope or hype? *Trends in Plant Science* 16(7): 363-371



This guidebook provides information on 22 technologies and options for adapting to climate change in the agriculture sector. It describes what policy makers, development planners, agriculture experts and other stakeholders in countries should consider while determining a technology development path in agriculture. NGOs, rural communities and agricultural practitioners could examine and include appropriate options in their portfolios of technologies and options for agriculture. The guidebook is expected to stimulate further work on identifying options for climate change adaptation in the agricultural sector in different parts of the world. This guidebook has been co-authored by Rebecca Clements, Alicia Quezada, and Juan Torres from Practical Action Latin America and Jeremy Haggard from the University of Greenwich, UK. They have extensive field experiences and strong expertise in supporting such activities in developing countries.



UNEP Risø Centre
Risø DTU National Laboratory for Sustainable Energy
<http://www.uneprisoe.org/>
<http://tech-action.org/>